NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN ANALYSIS OF GUNNER SHOT SELECTIONS AND PERFORMANCE AGAINST A SIMULATED MOVING TARGET

by

Ephraim Martin IV

June 1984

Thesis Advisor: Harold J. Larson

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An Analysis of Gunner Shot Selections and Performance Against a Simulated Moving Target

by

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Captain, United States Army
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

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NAVAL POSTGRADUATE SCHOOL
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I. INTRODUCTION

Marksmanship is a skill acquired through learned application of fundamental techniques peculiar to each weapon target scenario. A rifleman firing offhand at a bullseye practices breath control and an even trigger pull as the sight reticle dances in small ovals over the target mirroring the movement of the gunner's body. His goal is to keep the reticle moving around the desired impact point. He knows that he cannot keep the weapon perfectly still but practice has taught him to anticipate the instant in time when an even deliberate trigger pull and perfect target alignment will occur simultaneously. This technique allows some expert riflemen to place shot after shot into the target as accurately firing offhand as if they were firing from a bench rest. Some would credit such performance with superhuman ability but it is in fact a product of concentration and the basic principles of rifle marksmanship. In this simple example the gunner is able to do well because he learns to judge when his motion has characteristics that experience has taught him will produce the best shot groups. He has learned the rules of when to shoot . The simpler the weapon and the task assigned to it the easier are these rules of good marksmanship to catalog and verify. Unfortunately many modern weapons and weapon systems do not fall into this category. The principles that lead to the making of an expert gunner who uses a computer assisted leading system and laser range finders all mounted on a sophisticated platform and employed against mobile targets are not so easy to define and harder to verify. In many instances the gunner himself does not fully comprehend what principles he follows to do well, what aspects of target motion he keys on when deciding to shoot. The procedures followed herein suggest a method of doing so. Given an accurate well controlled experiment with clean relevant data some principles of good marksmanship for a complex weapon can be inferred and can be given some degree of credibility through statistical analysis.

The experiment which provided the basis for this analysis pitted a trained gunner in an actual weapon system against a simulated moving target. The weapon system used was a tank with a linear lead fire control system which in theory applies gun tube lead against a moving target to compensate for target motion during the time of flight of the round. The actual mechanics of this system are more complicated than this and are not the object of the analysis. It is relevant in that trained gunners such as those used in the experiment are assumed to have learned, to some degree, how to use the characteristics of this system to achieve better hit performance. A goal of the analysis is to establish a relationship between hit performance and target motion when using such a system.

The target presented was a laser dot projected onto a grey screen and moved back and forth on the screen by a moving target simulator according to a precise template. The template or target path is a set of corresponding position at time coordinates which represent the positions at given times of an actual target as viewed along a general axis of advance. This position at time plot is derived by measuring lateral displacement of an actual target vehicle as it advances toward an observer. In this convention the motion of the dot represents the apparent lateral motion of the actual target. In the experiment the dot moved laterally only and range did not appear to change although it was simulated in the magnitude of the lateral motion of the dot. Specifically, a true change in the lateral position of the target of twenty meters might be represented by moving the dot ten inches on the screen at a simulated range of 1000 meters versus five inches on the screen at a simulated range of 2000 meters. In either instance the size of the dot would not change. The physics of this simulation involved precise curvature of the screen and conversion of meters moved by the target to radians traveled on the screen. These procedures are not under study and it was assumed that the motion of the dot accurately simulated the apparent lateral motion of a target.

With these points in mind one trial of the experiment can be described as follows. A gunner is placed in a tank. He is told that a point of light will appear on the grey screen which he views through his target reticle much as one would view an object through a pair of binoculars. He is told to track the target and to pull the trigger when he feels his tracking will give him the best chance of hitting the target. With these instructions the gunner puts his crosshairs on the laser dot and moves the crosshairs to stay on the dot which is moved by the machine as described above. According to his own criteria the gunner periodically pulls the trigger, supposedly when he feels he has the best chance of hitting the target. A major goal of the analysis is to determine if gunners have some selection criteria in terms of the target motion and if so to describe it in a usable way.

Results from sixteen trials like the one described were examined. Each of two gunners conducted two trials at four different ranges presented in random order. For each trial the times at trigger pull were recorded and a corresponding probability of hit was computed. For future reference it is emphasized that the time at trigger pull has a one to one correspondence with the time in the target's motion history. By this fact the target motion parameters in the neighborhood of trigger pulls can be estimated as will be discussed later. The probability of hit was computed as a part of the experiment using a bivariate normal distribution to account for round to round dispersion.

The motion parameters provided by the experiment were the first and second derivatives of the position at time data which was used to move the target dot. As earlier stated this position at time data has its origin in the measurements taken from the movement of an actual target vehicle. To clarify this point, picture a target vehicle moving towards an observer. View this scene from above overlaying a fixed coordinate system covering the limits of the vehicle's movement . Locate the observer on the x-axis at some point beyond the stopping point of the vehicle where he can discern only lateral movement of the vehicle. Let the y-axis represent the distance in meters to the right (+) or left (-) of the origin that the observer views the target. Let the x-axis represent the corresponding time in seconds at which the position observation occurs with time zero being the vehicle's starting point and time final being the vehicle's stopping point. Using this scenario record the position of the target vehicle at discrete time points and you will have duplicated the raw data which formed the basis for the movement of the target dot. The actual position at time data used in the experiment was a refined form of this raw data consisting of a position measurement every .01 second. A graphical plot of this data is shown at Figure 1.1 . Bear in mind that this plot represents over 21500 data points. To picture what gunners in the experiment observed hold this graph canted at eye level and look toward the origin from the end of the x-axis. Now visualize this graph collapsed onto the y-axis and the points presented one at a time in proper time sequence as a point of light on a grey background. What you would see is a point of light moving back and forth with varying ranges of motion . This is what gunners in the experiment observed as the target motion.

The apparent velocity of the target dot was computed by the experiment as the first derivative of the position at time plot. The mathematics of this computation are relevant to understanding the analysis. Given n position measurements and n corresponding times the difference between pairs of adjacent measurements was computed. These computations give (n-1) changes in position over a corresponding change in time which allow computation of the instantaneous velocity estimates for the periods covered, each of which is .01 second in length. The actual velocity estimates are centered, equally weighted, 31 point averages of the velocity estimates surrounding any given point. Using this method of computation (n-31) velocity estimates were computed. A graphical representation of the target velocity computed by the experiment is shown at Figure 1.2 . As this graph shows, the velocity computed by the experiment was signed negative denoting right to left crossing of the target dot and positive denoting left to right crossing of the target dot. The absolute value of this velocity represents true velocity and is shown at Figure 1.3 .

The target's true acceleration was computed as a part of the analysis as the first derivative of the target's true velocity and is shown at Figure 1.4 . The derivation of this data is addressed in the methodology section under motion parameters. Acceleration as computed for the experiment was not used as it did not readily correlate to conventional notation of vehicular acceleration.

In summary the experiment pits two gunners in a series of sixteen trials against a point target whose motion parameters can be accurately established. The experiment records the time of trigger pulls and accurately estimates the gunners' performance at each event. Using these times the motion parameters in the neighborhood of trigger pulls can be determined. Since the only stimulus is the motion of the target dot it is assumed that there is some characteristic motion which motivates the gunner to shoot. The analysis seeks to verify or refute this assumption . If the analysis supports the assumption then further effort will be made to define what characteristics of target motion motivate the gunner to shoot. In addition the analysis will seek to establish a relationship or lack thereof between the gunners' performance and the target motion at trigger pull.

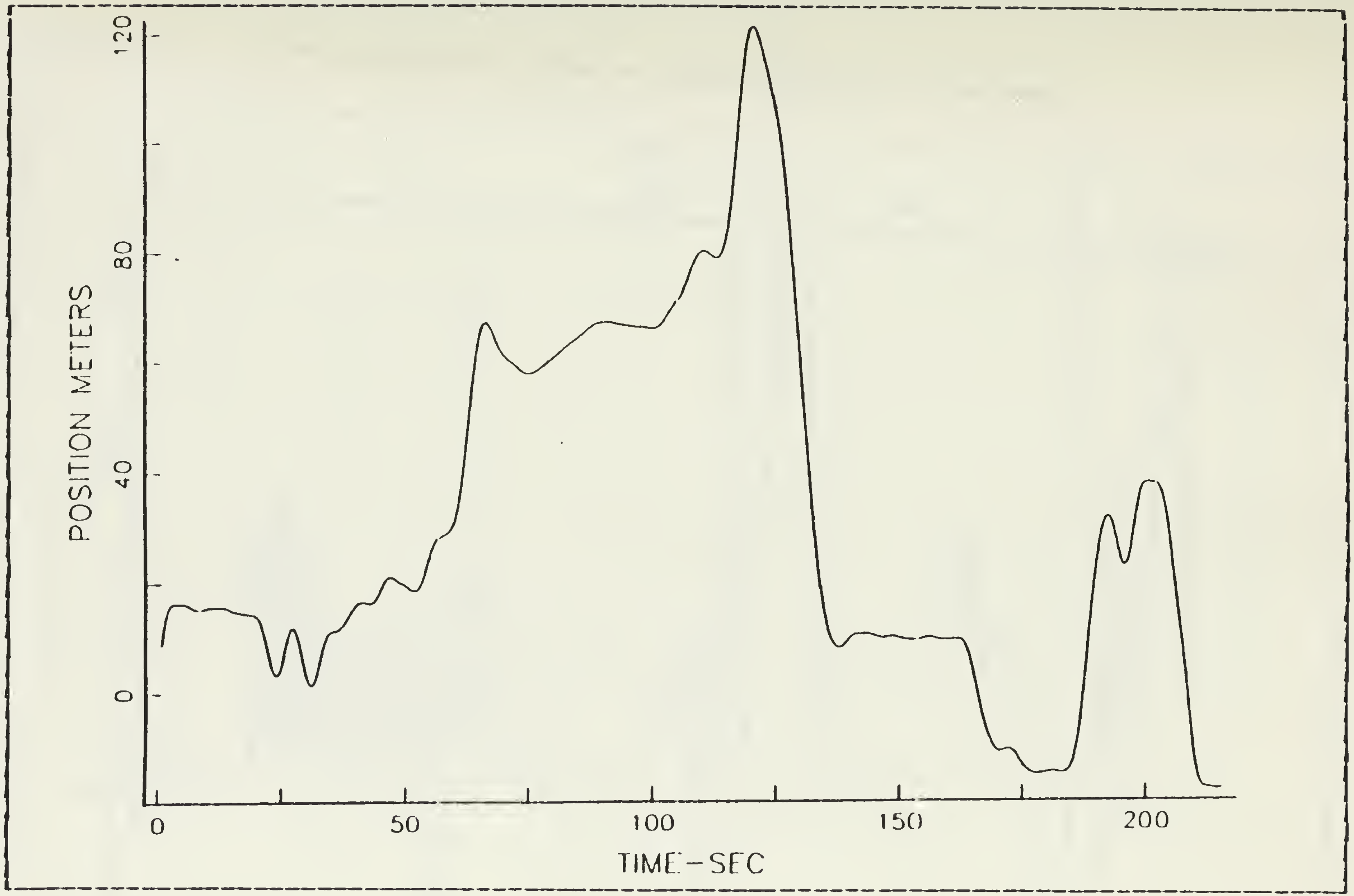


Figure 1.1 Target Position at Time.

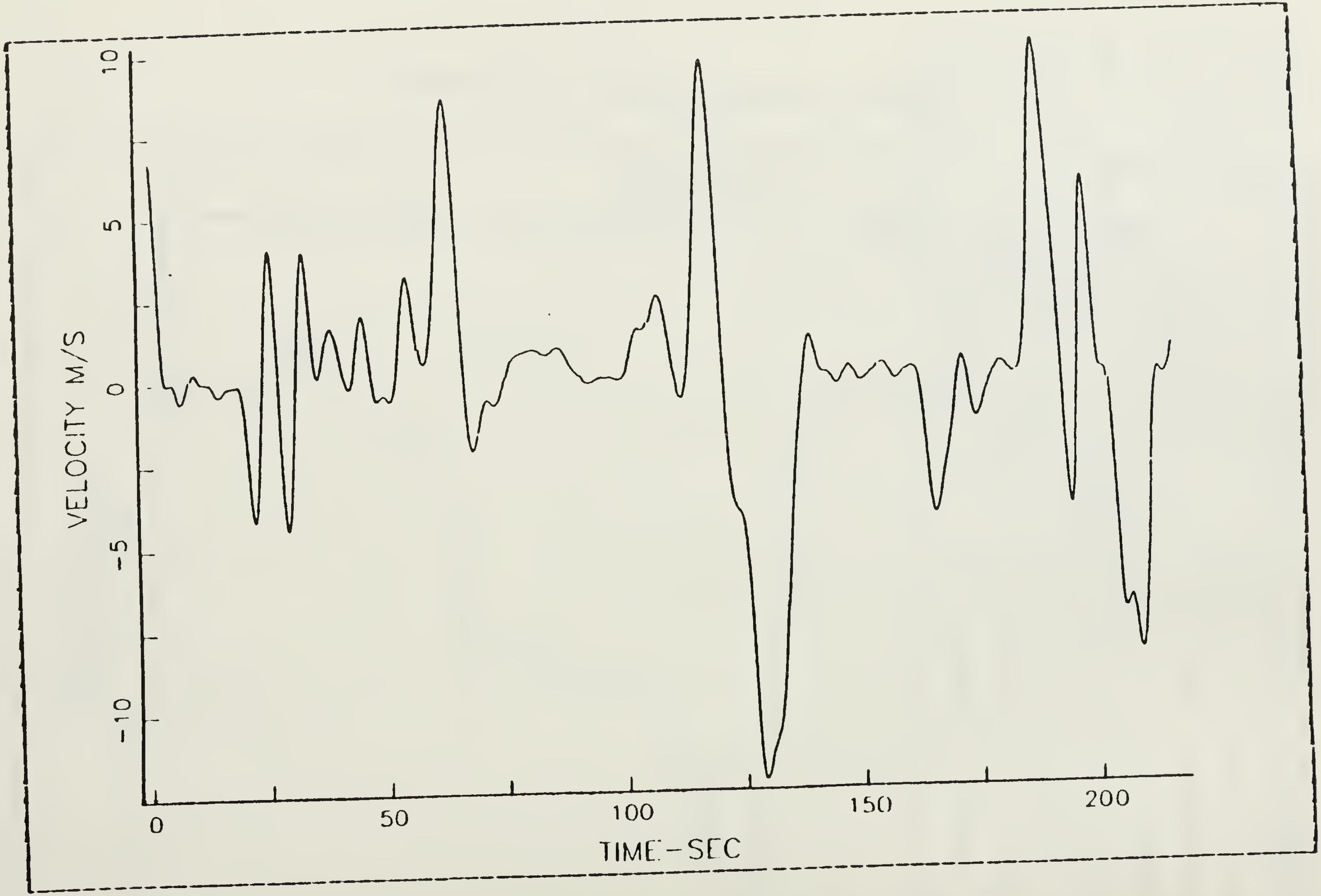


Figure 1.2 Target Velocity at Time as Computed by the Experiment.

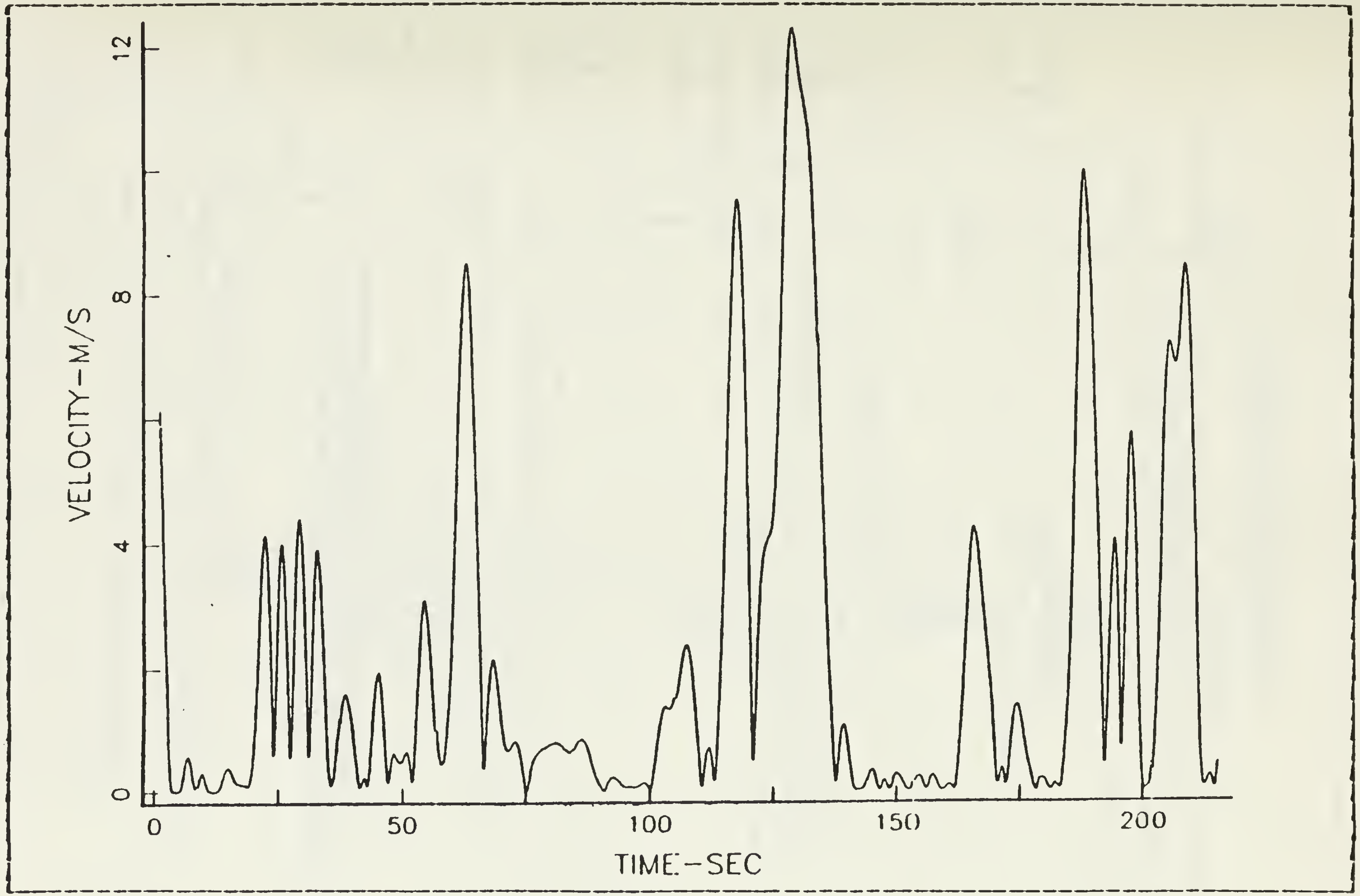


Figure 1.3 Target's True Velocity at Time.

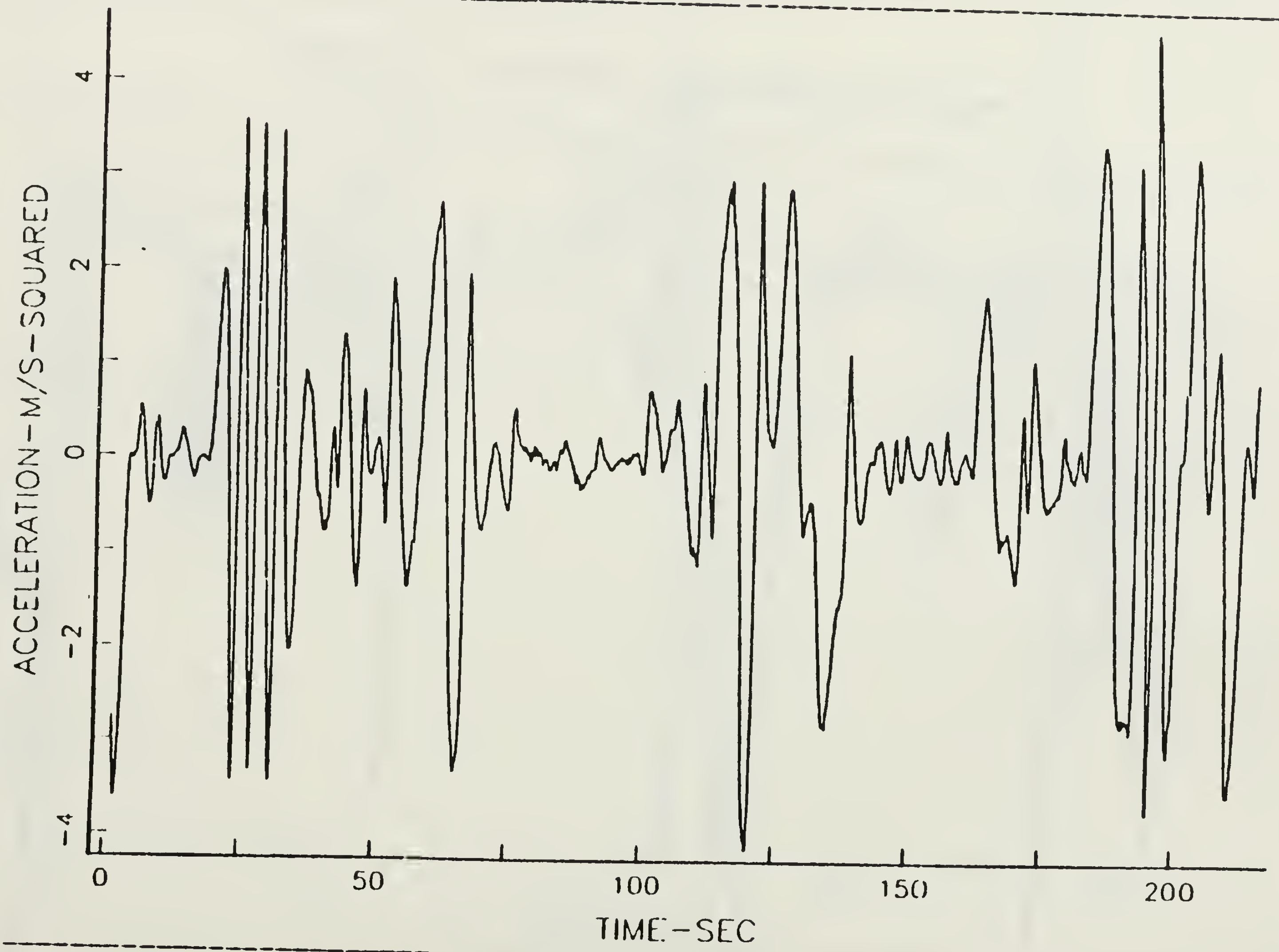


Figure 1.4 Target's True Acceleration at Time.

II. ANALYSIS METHODOLOGY

A. ORGANIZATION OF THE DATA FOR ANALYSIS

1. Motion Parameters

The data provided by the experiment relating to target motion consisted of a time, position, and velocity data vector each containing 21540 elements. There is a one to one correspondence between vectors. If the first element in the time vector is .25 seconds then the first element in the position vector is the target position at .25 seconds and the first element in the velocity vector is the target velocity at .25 seconds and so forth for each successive element in each vector. It is emphasized that all motion parameters are the apparent motion as observed by the gunner.

The velocity vector was computed by the experiment as previously described. Recall that the experiment provided a signed vector with the sign indicating the crossing direction of the target. True velocity was obtained as the absolute value of the signed velocity. True acceleration was obtained as the first derivative of true velocity. The procedure followed in this derivation duplicated the procedure used in the experiment to take the first derivative of the position vector. Given n estimates of true velocity the difference between adjacent estimates was computed. These changes in velocity divided by the corresponding change in time provided (n-1) estimates of instantaneous acceleration. The actual estimates for acceleration used in the analysis were 31 point, centered, equally weighted averages of the instantaneous estimates surrounding a given time. Under this method (n-31) estimates for acceleration were computed. The resulting true acceleration vector was signed positive to denote rate of increase in velocity and negative to denote rate of decrease in velocity of the target. This vector additionally retained a one to one correspondence with the other motion parameter vectors. As a minor point the derivation provided no estimate for the first sixteen or the last fifteen time periods. This proved inconsequential as the periods were short with duration less than .16 seconds and no observations occurred near them.

The majority of the analysis was concerned with the true velocity and acceleration of the target versus time. A segment of the estimates used for these values is shown at Figure 2.1 . It can be seen in this plot that the estimates used are reasonably accurate and conform to expected convention. As the velocity estimate increases the acceleration estimate remains positive. When the velocity estimate peaks and has zero slope the acceleration estimate approaches zero as expected. As the velocity estimate decreases the acceleration estimate remains negative. Extensive analysis and fitting of these vectors, or curves as shown, might improve their accuracy marginally but the analysis proceeded under the assumption that they provided sufficiently accurate estimates of the target's true velocity and acceleration.

In summary, the motion parameters used in the analysis were signed velocity, true velocity, and true acceleration. It is again emphasized that these values, in vector form, represented the apparent motion as observed by the gunner. Each vector consisted of 21509 data elements with a one to one correspondence to the time vector. Under this convention any given time of a trial could be matched with a corresponding estimate for signed velocity, true velocity, or true acceleration for the target at that time.

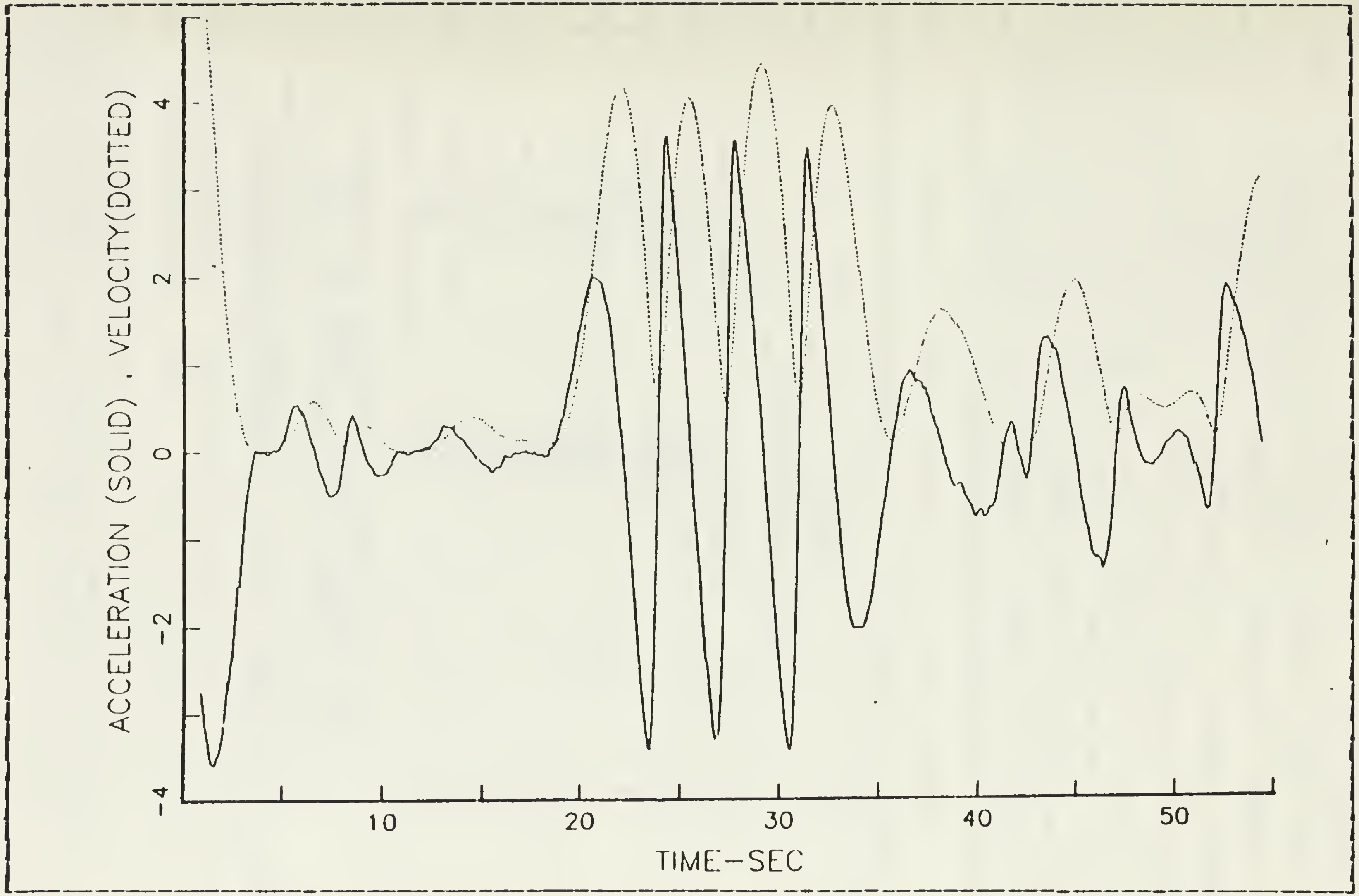


Figure 2.1 True Target Velocity and Acceleration at Time.

2. Gunner Data

The data provided by the experiment included the time at trigger pull and a corresponding probability of hit for sixteen trials. Each gunner conducted two trials at four different ranges giving a total of 295 observed trigger pulls as summarized at Table I . In addition to the data provided by the experiment, the target motion at trigger pull, at the time the gunner made the decision to shoot, and during the time the gunner formulated the decision to shoot, were derived from the motion parameter data vectors.

TABLE I

Data Organization

Trial	Gunner	Range (Meters)	Observations
1	1	1000	22
2	1	1000	16
3	1	2000	20
4	1	2000	29
5	1	2500	17
6	1	2500	25
7	1	3000	18
8	1	3000	21
9	2	1000	16
10	2	1000	19
11	2	2000	16
12	2	2000	17
13	2	2500	13
14	2	2500	17
15	2	3000	14
16	2	3000	15

Total Observations - Gunner 1: 168
Total Observations - Gunner 2: 127
Total Observations Gunner 1 & 2: 295

Note: Trial numbers are for reference only and do not indicate the order in which trials were conducted.

The motion parameters of the target at the time of trigger pull were extracted directly from the data. Since there was a one to one correspondence between the time vector and the motion parameter vectors a selection vector could be created which would select data elements from the motion vectors based on times or positions in the time vector. For example, if the gunner pulled the trigger at 5.21 seconds and 15.31 seconds these represented position 521 and 1531 in the time vector. Element 521 and 1531 could then be selected from the motion vectors to give the target's motion parameter values at these two trigger pulls. Because of the size of the vectors involved a program, shown at APPENDIX A, was written to create the selection vector. Using the selection vector method the signed velocity, true velocity, and true acceleration at the time of trigger pull for each trial were selected directly from the appropriate vectors. For the sake of exactness it is noted that only the signed velocity was actually extracted using the selection vector. Here, as throughout the analysis, true velocity was obtained as the absolute value of the signed velocity when needed. This point will not be reiterated but applies whenever true velocity is addressed.

The motion parameters of the target at the time the gunner made the decision to shoot were derived from the motion parameter vectors. Research in the human factors field indicates that a subject faced with a visual stimulus with little noise and a go/ no go decision has approximately a .2 second delay between the decision to act and manual execution of that decision [Ref. 1: p. 198]. These are the conditions faced by the gunners in this experiment. Taking this into account and allowing for some variation a program, shown at APPENDIX A, was written which selected values from the desired motion vector during the period .18 to .22 seconds prior to each trigger pull and computed the average of these values. This average value was then used as the estimate for the particular motion parameter in the neighborhood of the decision point to shoot. In this manner the estimates for the target's true velocity and acceleration at the time of decision to shoot were derived from the data for each trial.

The target's motion during the time the gunner was formulating the decision to shoot was derived in a similar manner. A subject faced with a continuous visual stimulus, such as a moving target, can sample from the stimulus approximately once every half second [Ref. 2: pp. 61-63]. Thus, what an observer interprets from a visual stimulus will be a function of snapshots taken in half second windows of time which will hereafter be called sampling windows. Using this basis the gunners' sampling windows were defined as half second time segments begining .2 seconds prior to trigger pull. In this convention sample one was defined as the period .2 to .7 seconds prior to trigger pull and is the last sample the gunner took prior to making the decision to shoot. A program, shown at APPENDIX A, was written which selected values from the specified motion vector during any half second interval specified. The program averaged these values and this average provided the estimate for the motion parameter during the sample window specified. Using this procedure estimates for the target's true velocity and acceleration during the four sample windows prior to the decision to shoot were derived for each trial. These estimates were assumed to be the last four samples of the target's motion which the gunner observed prior to making the decision to shoot.

These are in summary the procedures used to compile what is called the gunner data. To recap, the gunner data consists of the following.

(1) Time of trigger pull.
(2) Probability of hit at trigger pull.
(3) The target's true velocity, signed velocity, and true acceleration at the time of trigger pull.

(4) The target's true velocity and acceleration at the time the gunner made the decision to shoot.

(5) The target's true velocity and acceleration during the time the gunner formulated the decision to shoot.

3. Motion Parameter Cells

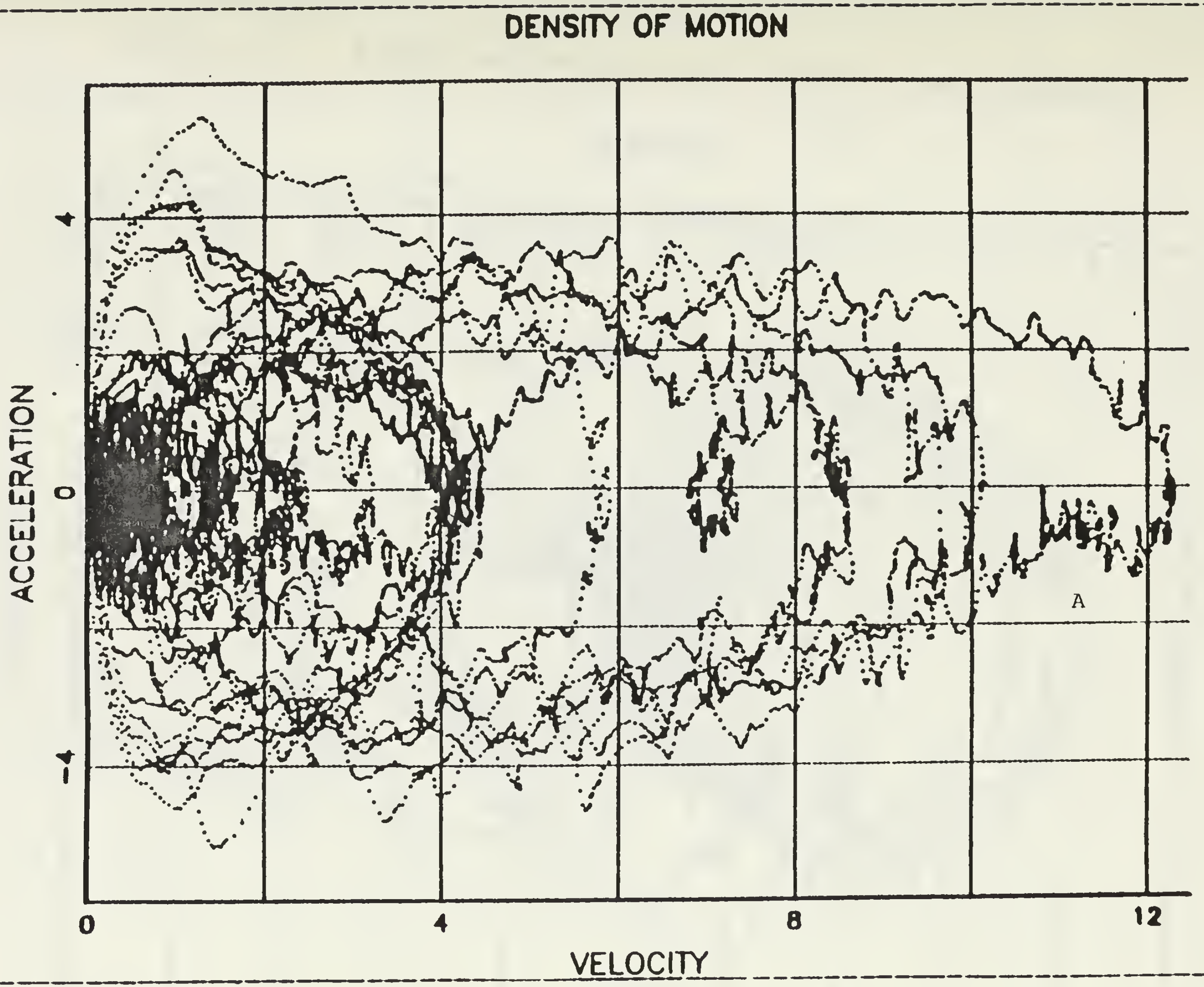
The sample space for the analysis of target motion is defined as all 21509 estimates of target motion. An estimate of target motion in this context refers to the two dimensional parameterization of the target motion for any given instant in time covering the duration of the trial. The two dimensions refered to are velocity, (signed or true) and true acceleration. Using this definition the distribution of the target motion can be plotted in two dimensions as shown at Figures 2.2 and 2.3 Each of these plots consists of 21509 points and in an abstract sense they represent the density of the target motion which the gunner observes. Looking at Figure 2.2 each point on the plot estimates the target's true velocity and acceleration during .01 second of the total time history of 215.09 seconds. To expand this concept consider all the points in the square labeled A on the plot. This square will hereafter be refered to as a cell or motion parameter cell. Assume you count the total number of points in this cell to be 407. Since you know there are 21509 total points you can compute the proportion that are in cell A as .0185. You can further state that the target displayed motion with velocity between 10 and 12 meters per second and deceleration between 2 and 0 meters per second squared 1.85 percent of the time. In general, the denser the plot the more the gunner observed that range of target motion. By grouping all the two dimensional estimates for the target motion into cells with boundaries of velocity and acceleration, the target motion can be quantified. Using the same procedure for only the target motion at gunner selections the target motion in the neighborhood of trigger pulls can be analyzed using several statistical techniques. A program, shown at APPENDIX A, was written which computes the cell counts for any selected boundaries of velocity and acceleration. This program was used to compute the motion parameter cell counts for the sample space and the gunners' selections.

B. ANALYSIS OF TARGET MOTION

1. Establishing Gunner Selection Criteria

The first step in the analysis of the target motion was to determine if there was statistical basis for stating that the gunners had any selection criteria at all. To do this, the assumption was made that the gunners' selections were random. Given this assumption certain characteristics should appear in the observations, the existence of which can be tested using statistical procedures. If these characteristics do not appear then there is basis for assuming that the gunners' selections are not random but selective. This methodology was applied to two contexts of target motion.

First, the analysis examined the question of a selection preference in the crossing direction of the target which was specified by the sign of the signed velocity vector. Through a counting process the proportion of elements in the signed velocity vector less than zero was determined to be p=.506. This gives the proportion of time the target crossed right to left. The proportion of time the target crossed left to right is (1-p) = .494 . Using these proportions the observed and expected values for gunner selections could be compared as shown at Table II . With the exception of the first trial at 2000 meters for Gunner one there appears to be no crossing preference for either gunner. All trials were tested against the



DENSITY OF MOTION

Figure 2.2 Motion Parameter Cells.

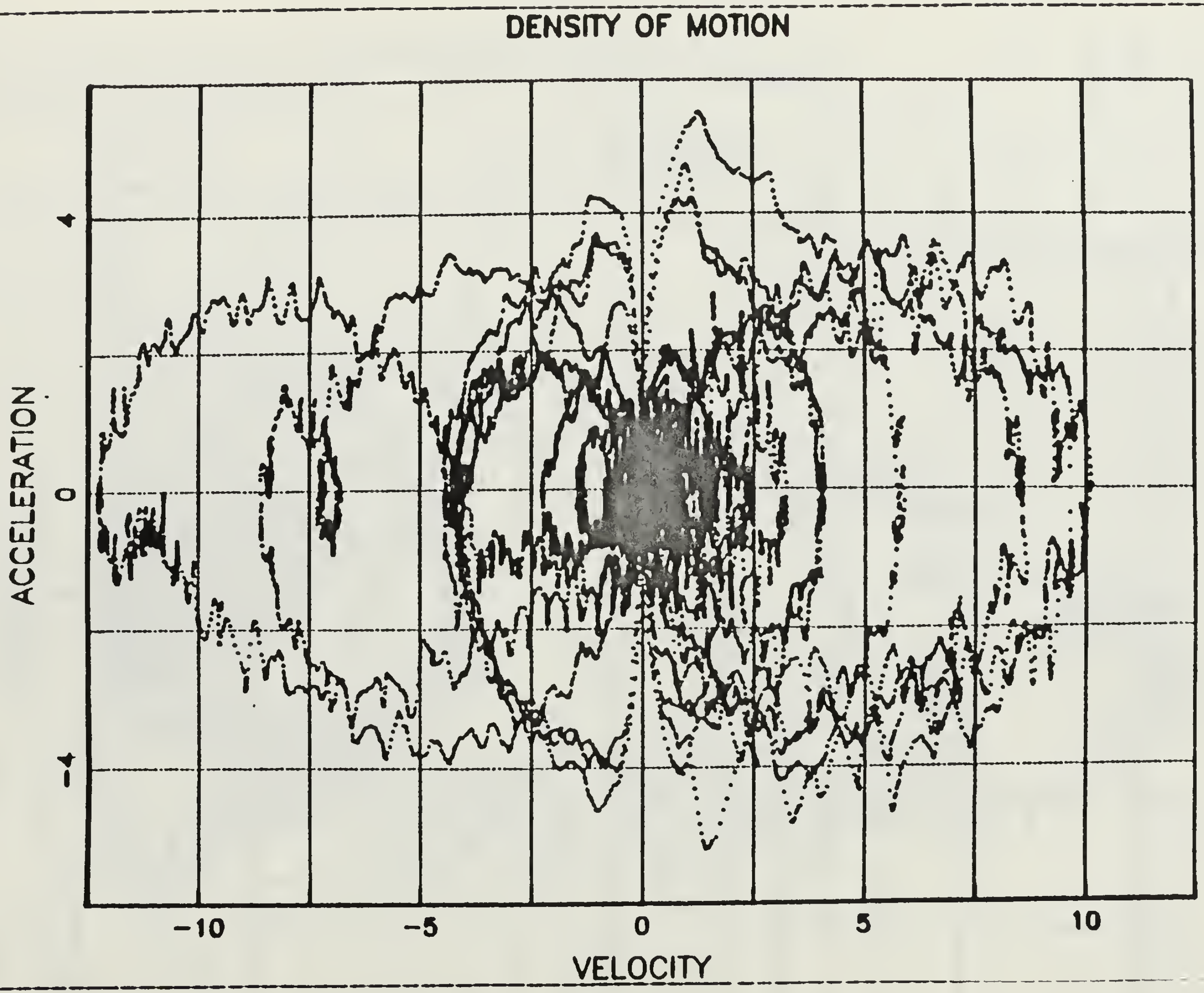


Figure 2.3 Motion Parameter Cells Using Signed Velocity.

assumption of no preference using the test of proportions [Ref. 3: pp. 528-534]. With the exception of the one trial noted, the results indicate no preference in crossing direction for either gunner with alpha equal .05 . Based on these results further analysis assumed no preference in crossing direction.

TABLE II

Crossing Preference Data

Gunner	Range	Total Obs.	Obs. (Exp.) Right-Left	Obs. (Exp.) Left-Right
1	1000	22	13 (11)	9 (11)
1	1000	16	8 (8)	8 (8)
1	2000	20	5 (10)	15 (10)
1	2000	29	12 (15)	17 (14)
1	2500	17	8 (9)	9 (8)
1	2500	25	11 (13)	14 (12)
1	2500	18	8 (9)	10 (9)
1	2500	21	9 (11)	12 (10)
2	1000	16	6 (8)	10 (8)
2	1000	19	10 (10)	9 (9)
2	2000	16	8 (8)	8 (8)
2	2000	17	8 (9)	9 (8)
2	2500	13	7 (7)	6 (6)
2	2500	17	8 (9)	9 (8)
2	3000	14	8 (7)	6 (7)
2	3000	15	8 (8)	7 (7)

Same data - combining trials at the same range

Gunner	Range	Total Obs.	Obs. (Exp.) Right-Left	Obs. (Exp.) Left-Right
1	1000	38	21 (19)	17 (19)
1	2000	49	17 (25)	32 (24)
1	2500	42	19 (21)	23 (21)
1	2500	39	17 (20)	22 (19)
2	1000	35	16 (18)	19 (17)
2	2000	33	16 (17)	17 (16)
2	2500	30	15 (15)	15 (15)
2	3000	29	16 (15)	13 (14)

Same data - combining trials for the same gunner

Gunner	Range	Total Obs.	Obs. (Exp.) Right-Left	Obs. (Exp.) Left-Right
1	ALL	168	74 (85)	94 (83)
1	ALL-	148	69 (75)	79 (73)
2	ALL	127	63 (64)	63 (63)

Note: ALL- excludes the first trial at 2000 meters.

The second objective relating to selection criteria was to assess whether the gunners had any overall preference in target motion. Did they screen out certain ranges of motion and look for others as they engaged the target? This question was addressed by grouping the gunners' selections at trigger pull and the sample space into motion parameter cells and comparing the two distributions. In this manner one could observe the proportion of selections by the gunner in a certain range of motion against the proportion of opportunities available and assess whether or not an overall difference exists. Because of the small sample sizes for individual trials this portion of the analysis was conducted in two stages.

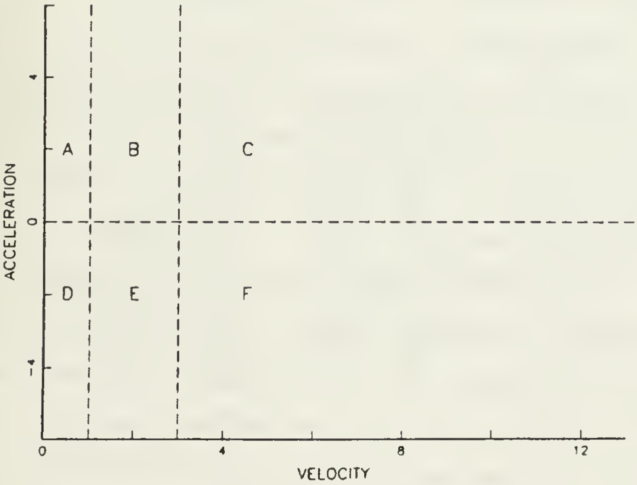
In the first stage the observations for each trial were grouped into the motion parameter cells shown at Table III . A subjective analysis of this data suggests no significant difference between trials at the same range or between ranges with the same gunner. There appears to be a significant difference between the two gunners however. This analysis was confirmed using a contingency table test [Ref. 4: pp. 153-170]. The hypothesis of no interaction due to trials with the same gunner could not be rejected. The hypothesis of no interaction due to trials between gunners was rejected at the .05 level. Based on these results it was assumed that trials within the same gunner could be combined with no significant degradation in the validity of the analysis. These results advised against any analysis based on trials combined between gunners.

In the second stage the combined observations of all eight trials for each gunner were grouped into the motion parameter cells shown at Table IV as were the observations for the total target motion. Reading the table note that cell A for Gunner 1 has an entry of 6 for the expected number of shots. This value is computed as the product rp

TABLE III

Comparing Individual Trials

Gunner	Range	A	B	C	D	E	F	Total
		Motion Parameter Cell						
1	1000	9	0	2	4	3	4	22
1	1000	3	1	0	5	3	4	16
1	2000	5	1	1	5	4	4	20
1	2000	6	1	1	7	4	10	29
1	2500	6	0	1	2	3	5	17
1	2500	8	1	2	2	4	8	25
1	3000	3	1	2	4	4	4	18
1	3000	5	1	0	6	2	7	21
2	1000	2	1	2	5	3	4	17
2	1000	2	2	4	2	0	8	18
2	2000	2	1	2	1	1	9	16
2	2000	1	1	5	2	3	5	17
2	2500	1	0	3	2	1	6	13
2	2500	1	1	3	2	4	6	17
2	3000	2	1	1	1	3	6	14
2	3000	0	1	3	2	4	5	15
1	1000	12	1	2	9	6	8	38
1	2000	11	2	2	12	8	14	49
1	2500	14	1	3	4	7	13	42
1	3000	8	2	2	10	6	11	39
2	1000	4	3	6	7	3	12	35
2	2000	3	2	7	3	3	14	33
2	2500	2	1	6	4	5	12	30
2	3000	2	2	4	3	7	11	29
1	ALL	45	6	9	35	27	46	168
2	ALL	11	9	23	17	18	49	127



Cell Boundaries

Cell	Vel.	Acel.
A	0 - 1	-6 - 0
B	1 - 3	-6 - 0
C	3 - 13	-6 - 0
D	0 - 1	0 - 6
E	1 - 3	0 - 6
F	3 - 13	0 - 6

where n is the total number of shots taken and p is the proportion of time the target displayed motion delineated by cell A. If the gunner's shots were random we would expect 6 to occur in the range of motion delineated by cell A. Reading down the column we see the actual number observed in cell A at shot is 4, at decision is 2, during the first sample window prior to decision is 0,and so forth. This data suggests that gunners do have a selection method because their observed choices differ substantially from the expected number of choices for several cells. These overall distributions were compared to see if they were the same using the Chi Square Goodness of Fit test [Ref. 4: pp. 189-199]. The hypothesis that the two gunners randomly selected times to shoot from the available opportunities was rejected, for each gunner, at the .05 level. In addition, the hypothesis that Gunner 1 selected times to shoot in the same ways as Gunner 2 was rejected at the .05 level. Based on these results it was assumed that gunners do have a selection method and that there is a difference in method between the two gunners.

2. Characterizing Target Motion

Having established evidence that gunners do have some selection criteria, graphical analysis backed up by statistical testing where feasible was used to clarify what it is. The graphs shown at Figures 2.4 and 2.5 show the target motion in the neighborhood of trigger pulls. Viewing these graphs in sequence from sample 4 to 3 to 2 to 1 to decision to trigger pull re-creates the overall snapshots allegedly taken by the gunner during the 2.2 second time history leading up to trigger pull. The graphs suggest an overall decrease in target motion during the time leading to trigger pull. The decrease in velocity is not so clear but the acceleration changes dramatically from positive to

TABLE IV

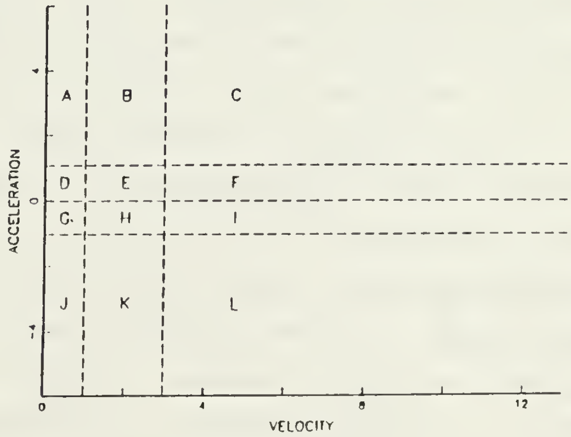
Comparison of Distributions

Gunner Selections verses Total Target Motion

	Motion Parameter Cell											
Gunner 1	A	B	C	D	E	F	G	H	I	J	K	L
Expected	6	21	3	37	12	2	43	13	3	5	20	3
Observed												
At Shot	4	2	2	41	10	1	28	19	4	7	38	12
Decision	2	2	1	33	9	3	39	24	4	1	40	10
Sample 1	0	3	1	30	13	2	44	27	8	1	29	10
Sample 2	0	6	3	22	27	9	47	26	12	1	12	3
Sample 3	0	22	10	22	34	10	44	15	4	2	3	2
Sample 4	1	49	12	32	17	2	35	9	3	2	4	2

Gunner 2	A	B	C	D	E	F	G	H	I	J	K	L
Expected	4	16	2	28	9	2	33	9	3	4	15	2
Observed												
At Shot	1	7	4	10	12	8	18	15	8	0	28	16
Decision	0	7	8	7	14	5	21	13	13	1	28	10
Sample 1	0	15	5	8	14	6	17	18	17	3	18	6
Sample 2	1	24	7	9	22	12	16	12	10	0	10	4
Sample 3	3	37	13	13	23	5	12	9	7	0	3	2
Sample 4	1	48	13	18	15	3	10	8	6	1	2	2

Cell	Vel.	Acel.
A	0 - 1	-6 to -1
B	1 - 3	-6 to -1
C	3 - 13	-6 to -1
D	0 - 1	-1 - 0
E	1 - 3	-1 - 0
F	3 - 13	-1 - 0
G	0 - 1	0 - 1
H	1 - 3	0 - 1
I	3 - 13	0 - 1
J	0 - 1	1 - 6
K	1 - 3	1 - 6
L	3 - 13	1 - 6



negative as trigger pull approaches. In real terms this suggests that the gunners look for points where the target speeds up and then slows down taking the shot as the target approaches zero acceleration or as it decelerates. This implies that gunners may be trying to match trigger pull with either constant velocity, zero target motion, or both.

To identify the specific ranges of motion preference for each gunner the proportion of total target motion for each motion parameter cell was compared against the proportion selected by the gunner using the test of proportions as outlined in Duncan. As an example, the number of selections in cell K by Gunner one at trigger pull is 38 as shown in Table IV . The proportion of gunner selections in this cell is then 38/(168 = total selections) or $\hat{p} = .226$. The proportion of total target motion in this cell is $p = .119$. The hypothesis that $p = \hat{p}$ is then tested and rejected at the .05 level indicating strongly that the proportion of selections in cell K by Gunner one is higher than expected. It is important to note here that gunner selections are assumed to be independent remembering that gunners did not have to make any selections. Gunners were told only to track the target and shoot when they felt they could hit the target. Using this procedure each cell for each time period from trigger pull to sample 4 was examined to determine which cells had selection counts higher or lower than expected at the .05 level or less. Figures 2.6 and 2.7 show the results of these tests. Each figure shows regions of motion selected more than expected as shaded areas while regions of motion selected less than expected are shown as cross hatched areas. All other areas had the expected number of selections. Both gunners avoid sharply increasing target motion and to a lesser degree sharply decreasing target motion. Both gunners give strong evidence of looking for the target to decelerate or for acceleration to approach zero. Several differences between the two gunners are also evident. Gunner 2 has fewer shots than expected in the neighborhood of zero motion. Gunner 1 displays this tendency but to a lesser degree. In addition, Gunner 1 has a narrower range of prefered motion than Gunner 2.

The boxplots at Figures 2.8 through 2.13 clarify these statements further. In each of these figures the distribution of the particular parameter is shown in boxplot format. [Ref. 5: pp. 58 - 62]. The box encloses roughly the interquartile range of the data with a circle indicating the mean and an asterisk the median. The X at the end of the whiskers indicates the main body of the data, approximately 95 per cent, while circles beyond the X indicate outliers. Figures 2.8 and 2.9 show the distribution of acceleration for Gunner 1 and Gunner 2 respectively. These indicate that both gunners look for target acceleration followed by deceleration during the time leading up to shot. Figures 2.10 and 2.11 show the distribution of velocity for both gunners in the same format. During the period leading to trigger pull for Gunner 2, target velocity remains fairly constant with a slight increase followed by a slight decrease as trigger pull approaches. Gunner 1 displays a greater tendency to look for decreasing velocity during the time preceeding trigger pull but the large number of outliers indicates that this may not be a very strong criteria by itself. Figures 2.12 and 2.13 show the magnitude of motion in the neighborhood of trigger pull. This term is somewhat contrived but logically so. The absolute value of acceleration plus the velocity of the target are summed to give a relative indicator of how much motion the target displayed at a given time. By combining these two variables in this way motion will appear large if either velocity or acceleration is high and larger when both are high.

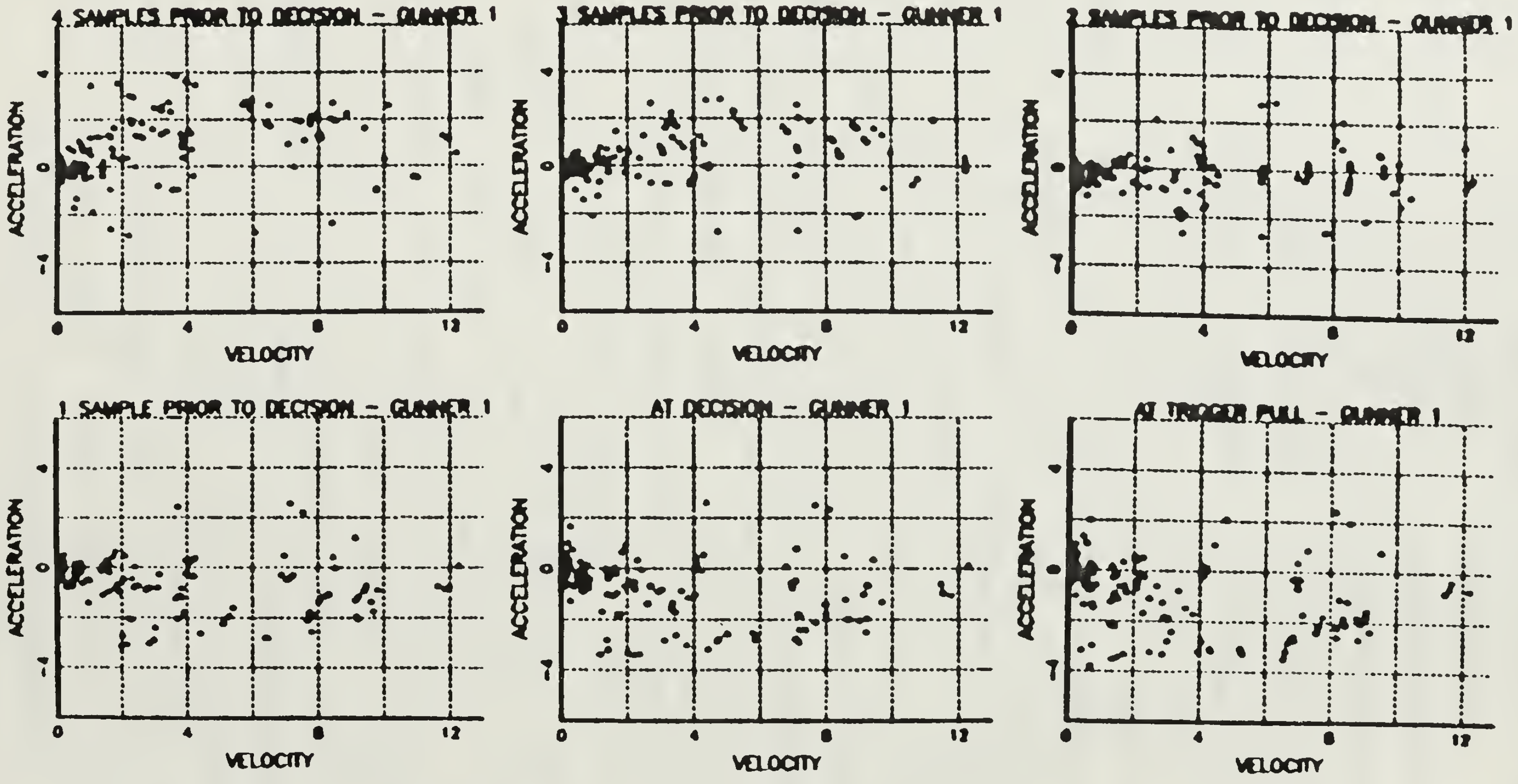


Figure 2.4 Gunner 1 Selections.

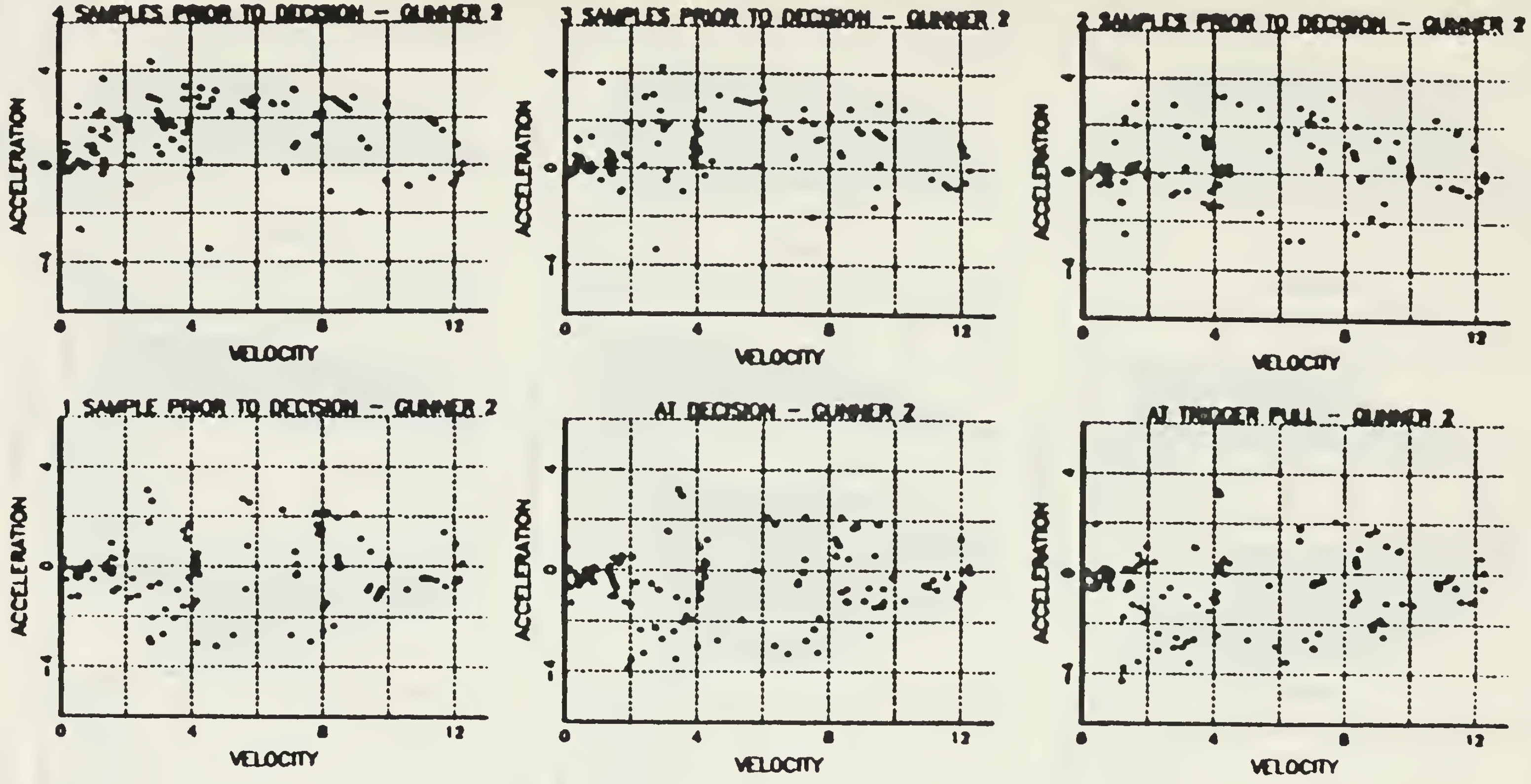


Figure 2.5 Gunner 2 Selections.

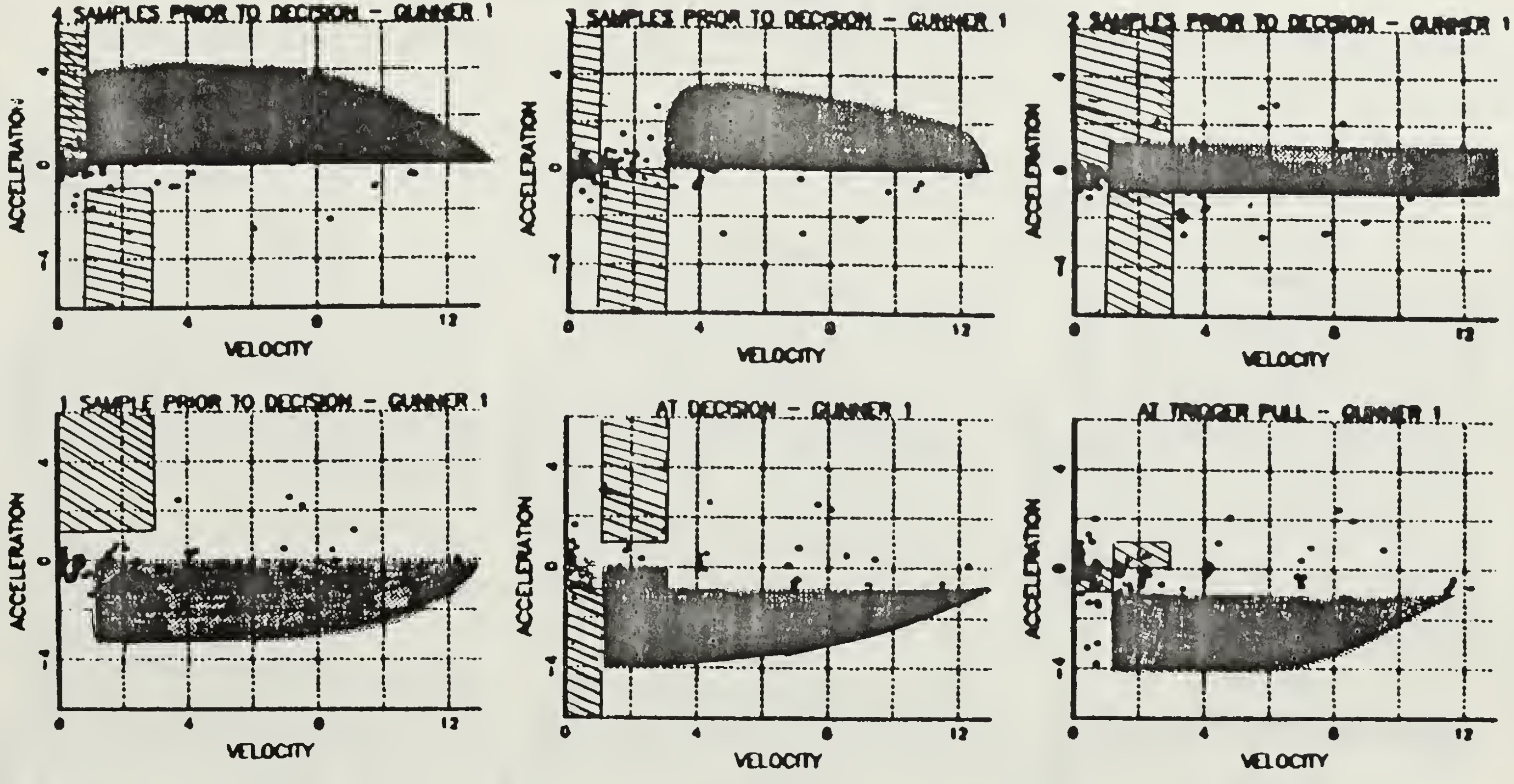


Figure 2.6 Gunner 1 Selection Method.

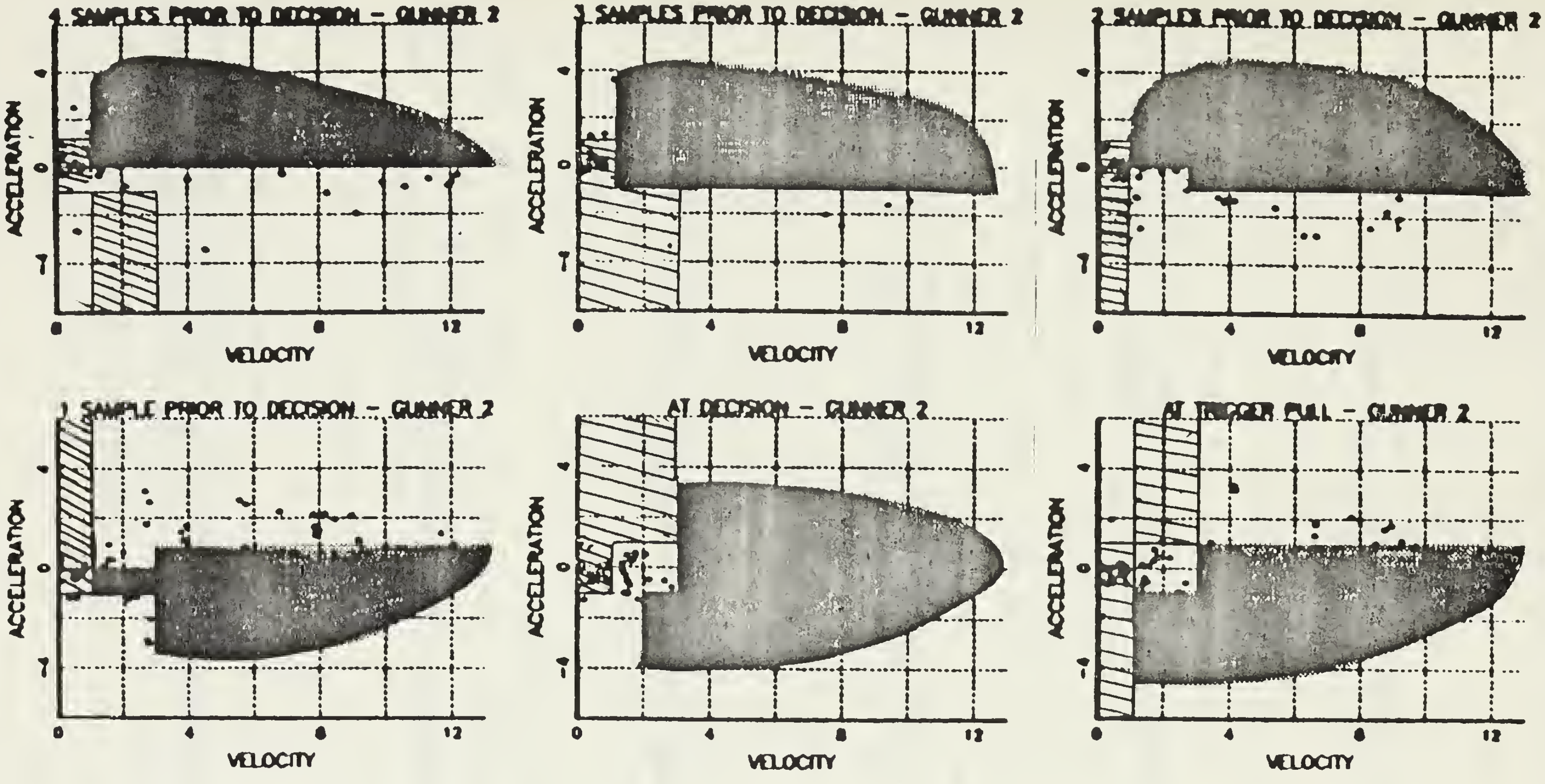


Figure 2.7 Gunner 2 Selection Method.

There is a clear tendency for both gunners to seek reduced target motion, in this context, at trigger pull. Gunner 1 appears to set tighter limits on how much motion he will allow but has a large number of outliers indicating there may be additional criteria other than strictly target motion which influence his decision to shoot.

Figure 2.14 shows the performance for both gunners. Gunner 1 made 168 shots, giving 168 values for P1, his probability of hit. Gunner 2 made 127 shots, giving 127 values for P2, his probability of hit. One can then denote the proportion of P1 or P2 values less than or equal to p for p between zero and one inclusive. The proportion of shots falling at or below any given value of PHIT can be determined from Figure 2.14 by picking a point on the plot and reading the proportion from the y-axis coordinate and the PHIT value from the x-axis coordinate. In this manner the dotted lines on the figure show that 50 per cent of Gunner 1's shots yield a PHIT value at or below .33 and 50 per cent of Gunner 2's shots yield a PHIT value at or below .22 . The plots and the statistics shown indicate that Gunner 1 shoots more often and does a slightly better job of picking shots. Gunner 1 shows a smaller proportion of shots achieving low PHIT values.

In summary the selection criteria can be stated as follows. Both gunners look for decreasing motion in general and deceleration or acceleration approaching zero in specific. There is a slight tendency for Gunner 1 to look for decreasing velocity, less so for Gunner 2. Both gunners screen out sharply increasing or decreasing motion. These statements are strongly supported through statistical and graphical analysis. As an intuitive observation, Gunner 1 seems to anticipate target motion better than Gunner 2 enabling more of his shots to fall in the neighborhood of zero target motion.

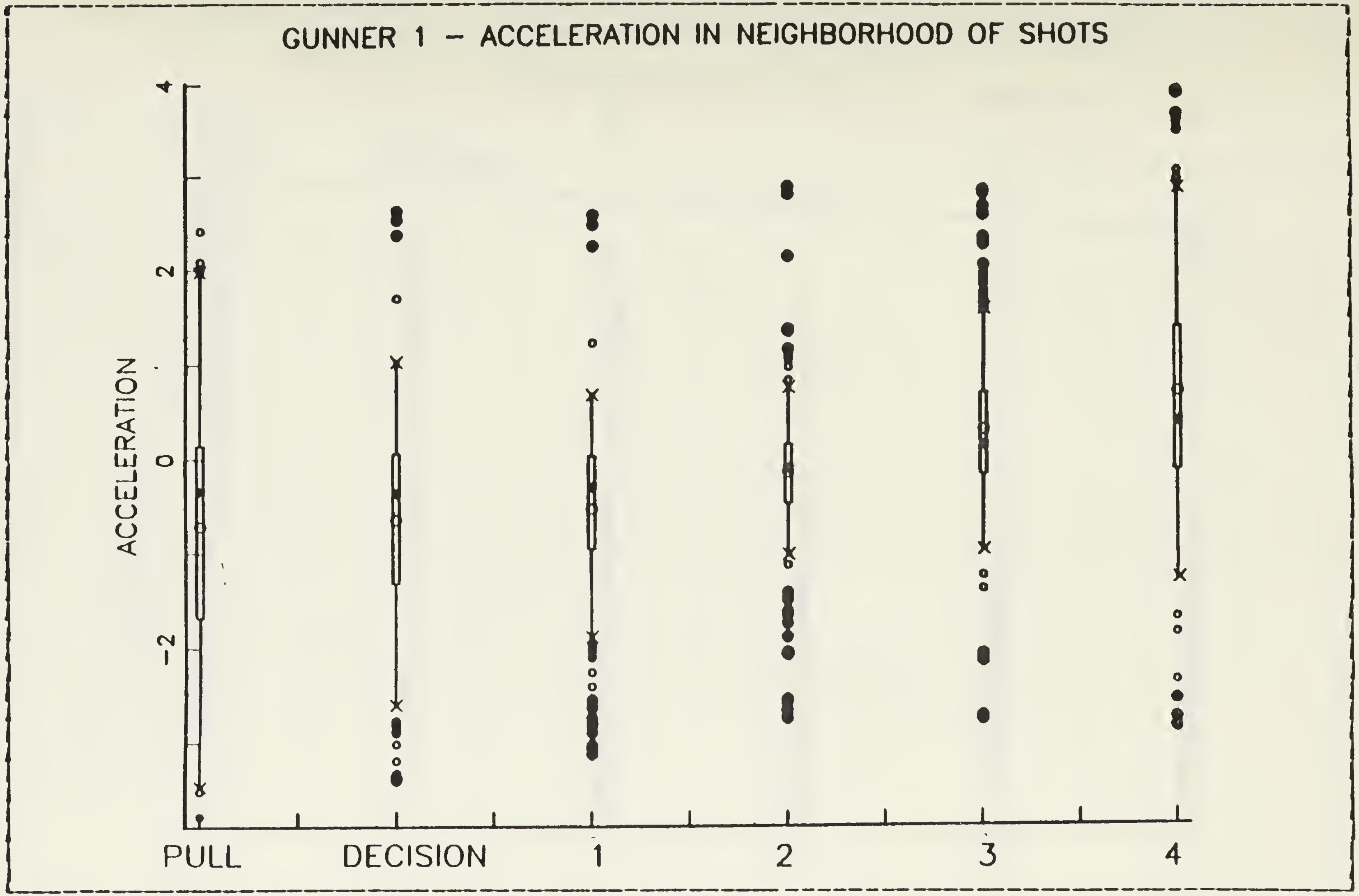


Figure 2.8 Distribution of Acceleration - Gunner 1.

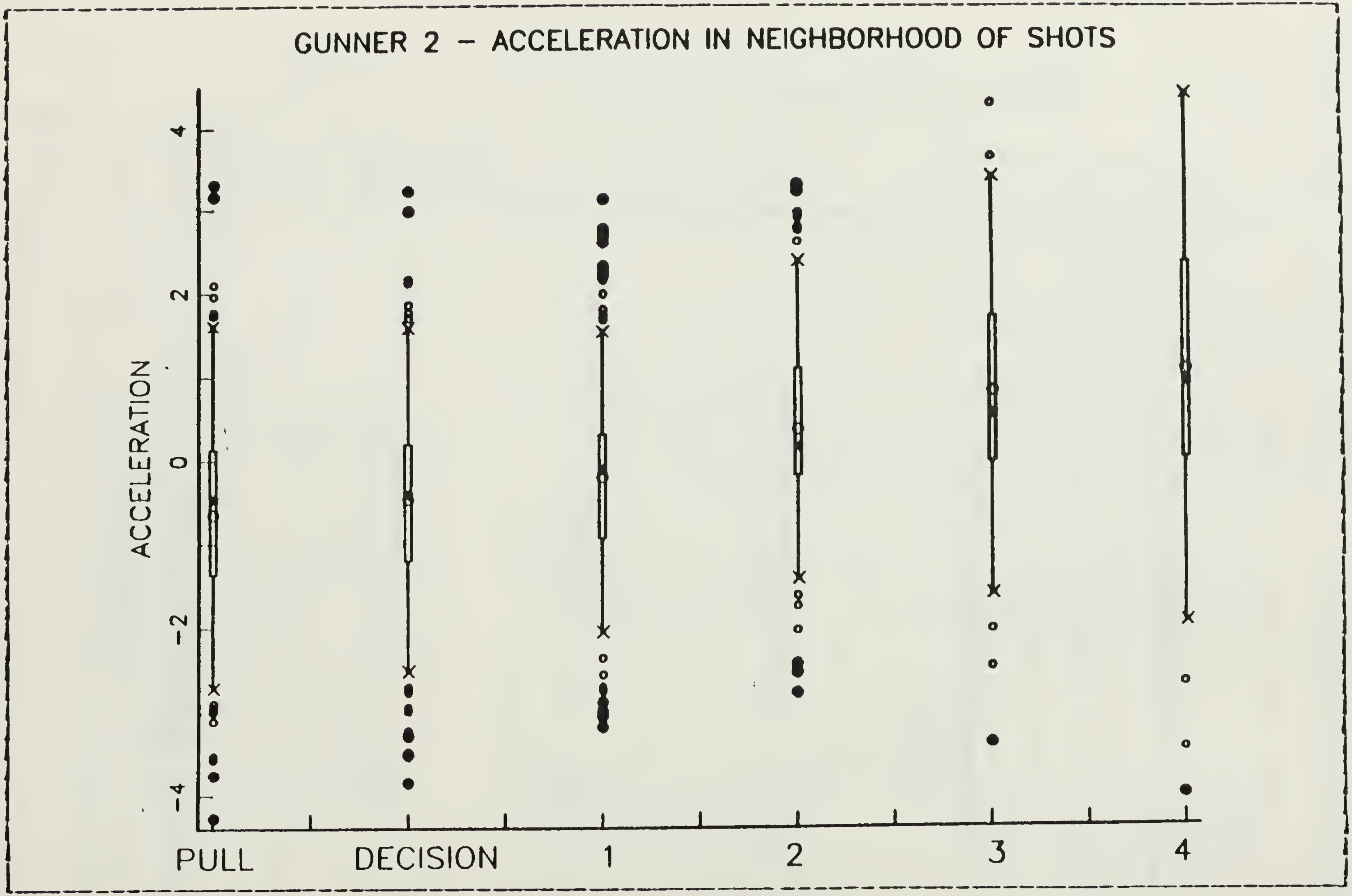


Figure 2.9 Distribution of Acceleration - Gunner 2.

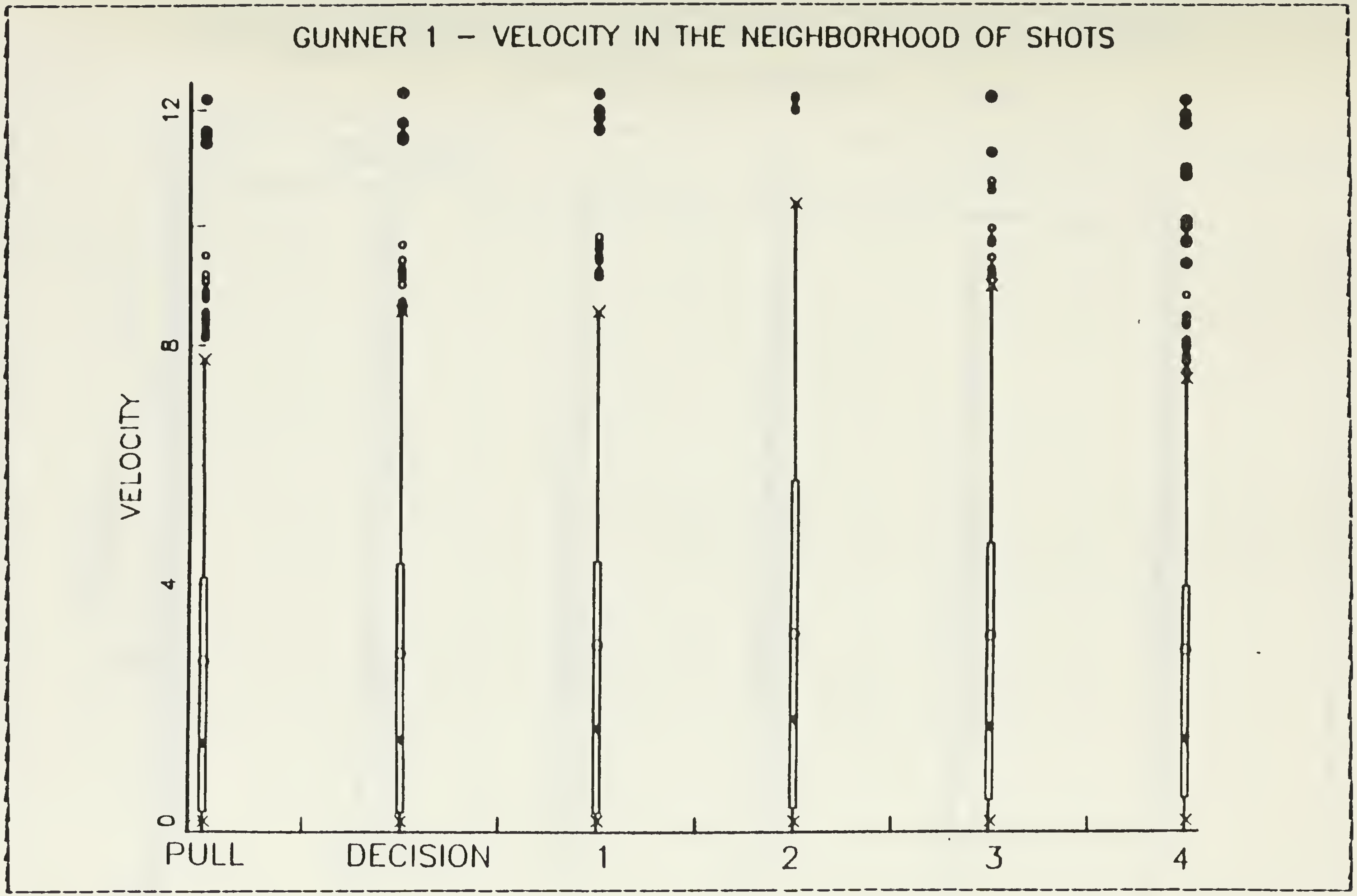


Figure 2.10 Distribution of Velocity - Gunner 1.

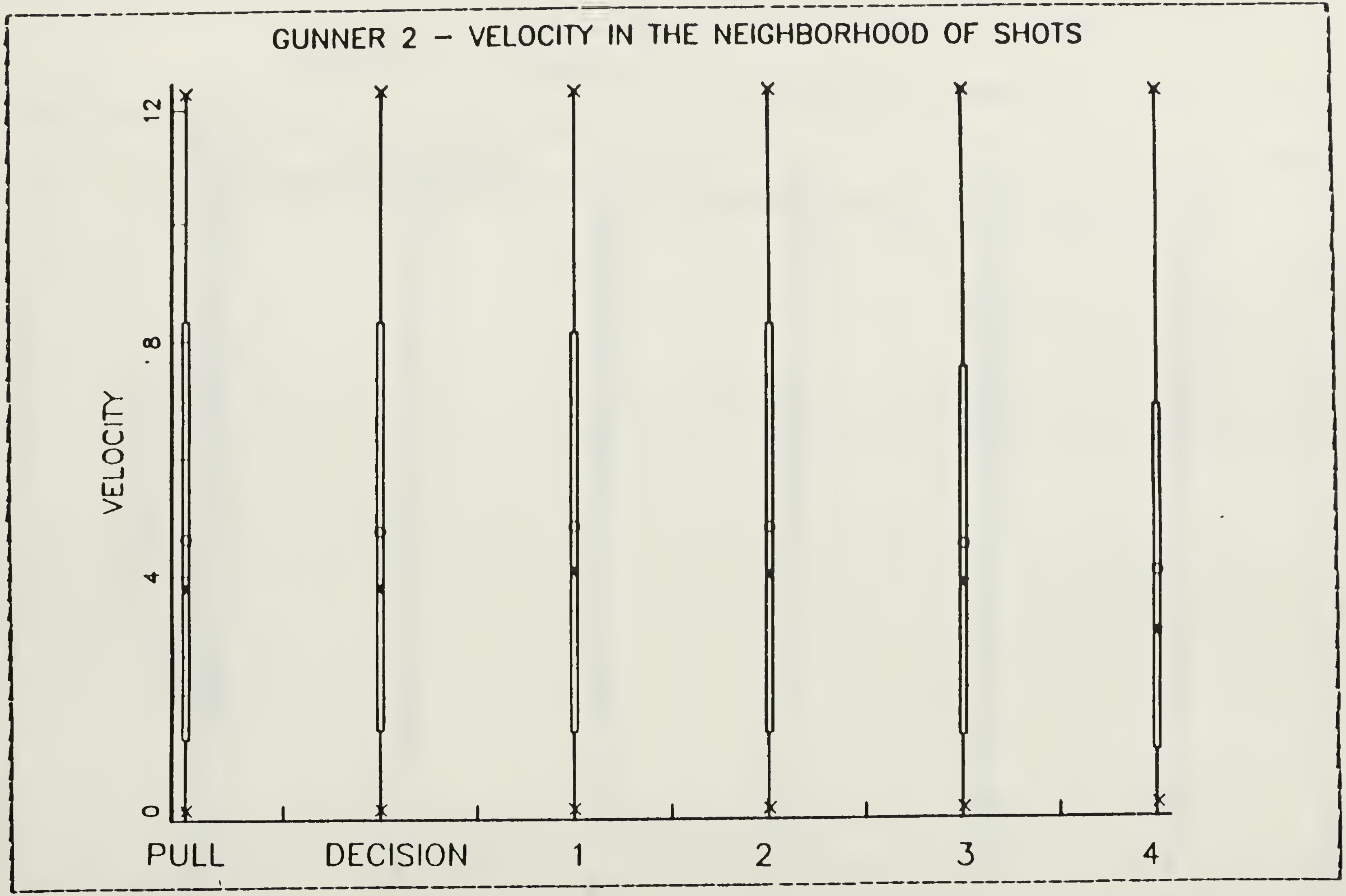


Figure 2.11 Distribution of Velocity - Gunner 2.

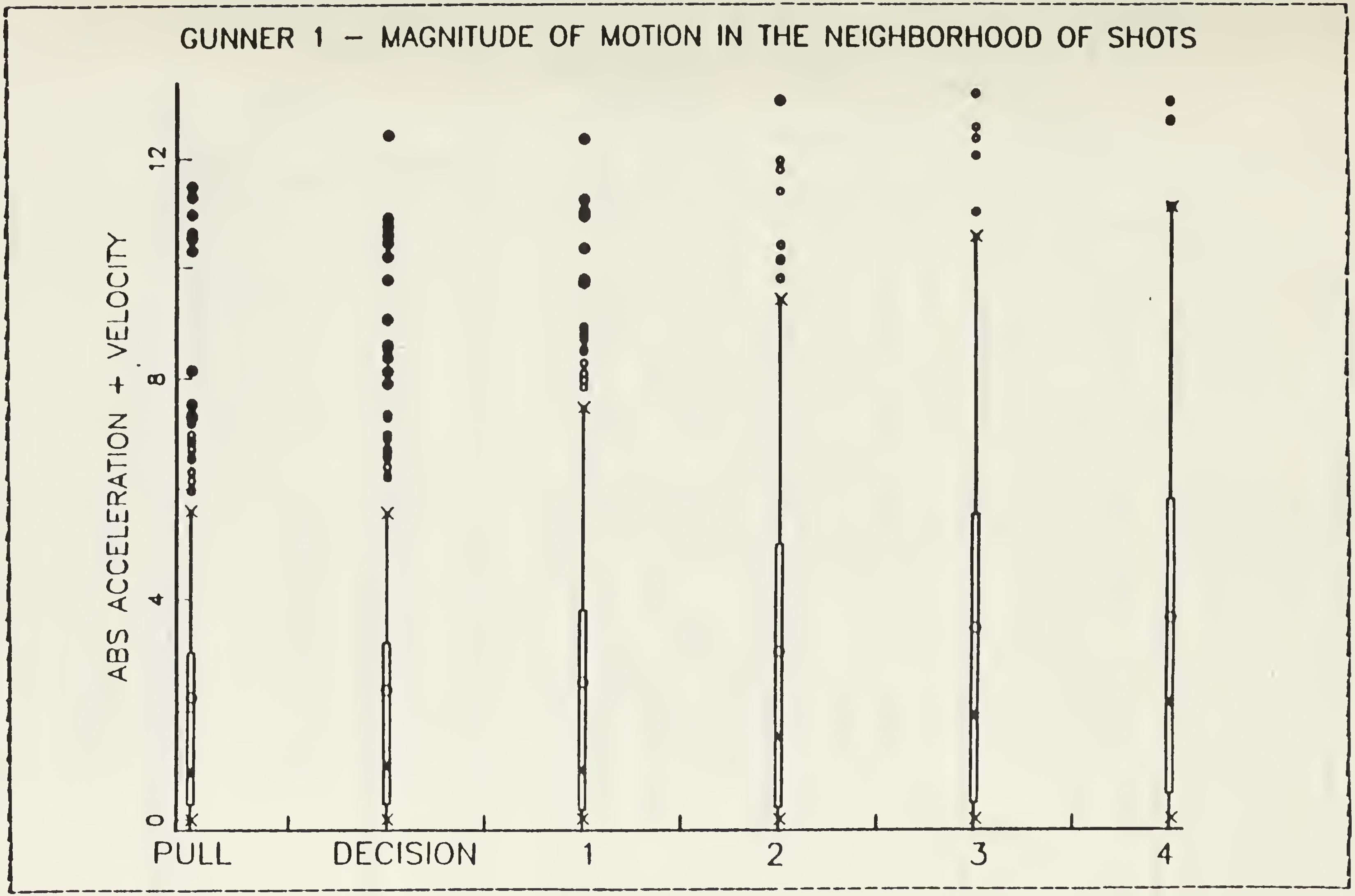


Figure 2.12 Distribution of Motion - Gunner 1.

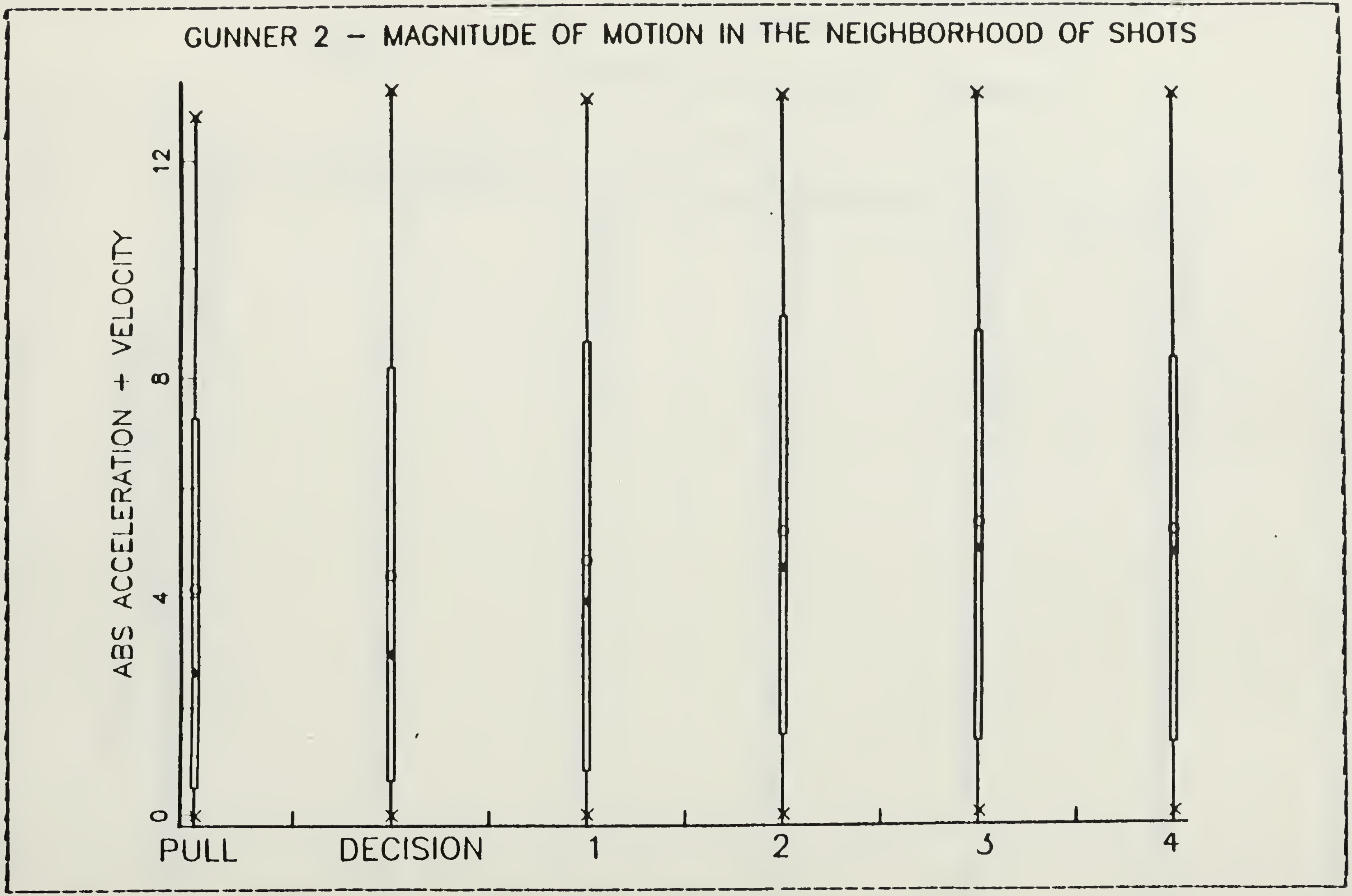


Figure 2.13 Distribution of Motion - Gunner 2.

C. MODELING GUNNER PERFORMANCE

Least squares multiple regression was used to explore the relationship between PHIT and the motion parameters. PHIT was treated as the dependent variable and true velocity and acceleration were used as the carrier or explanatory variables. A constant term was used in all cases since it was assumed that the gunners would achieve some level of PHIT greater than zero given a stationary target. The variable definitions shown in Table V will apply henceforth. Expanding on this table, X represents the vector of independent variables each being a vector with the same dimension as PHIT, the dependent variable. X0 is a vector of ones for the constant term in the regression. X1 might be V for the velocity associated with each PHIT value. X2 might be A for the acceleration associated with each PHIT value. X3, X4,... XN would be other functions of the motion parameters associated with each PHIT value. BETA is the vector of coefficients with BETA0 being the coefficient of the constant term, BETA1 being the coefficient for X1 and so forth for each independent variable.

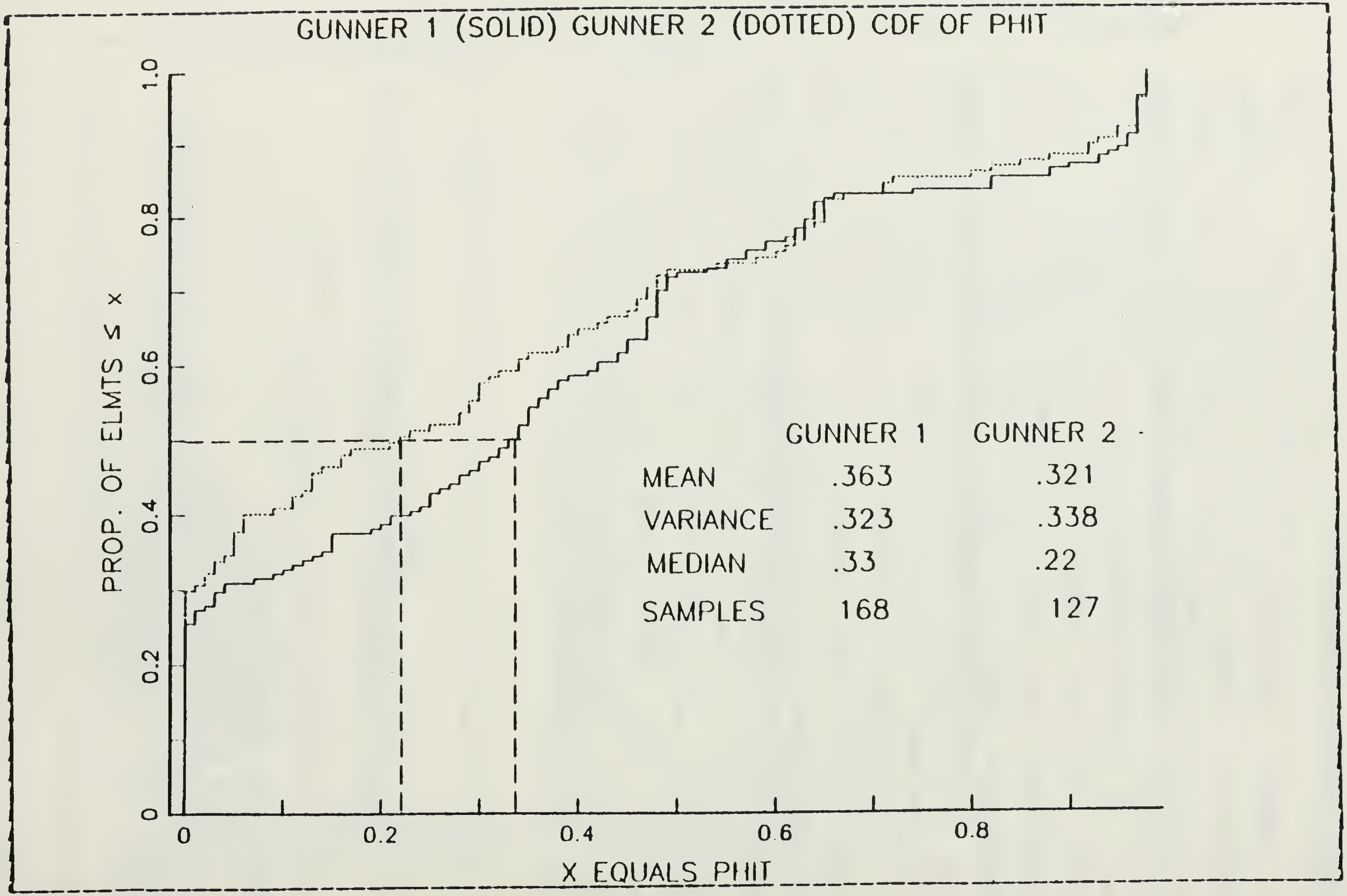
TABLE V

Variable Definition for Regression Models

Dependent Variable: PHIT = Probability of Hit

Independent Variables: X = X0 or X1 or ... XN
 X0 = I = A Vector of Ones
 V = True Velocity Vector
 A = True Acceleration Vector

Coefficients:
 BETA = BETA0, BETA1,...BETAN = Coefficients Vector
 BETA0 = C = Constant Term



	GUNNER 1	GUNNER 2
MEAN	.363	.321
VARIANCE	.323	.338
MEDIAN	.33	.22
SAMPLES	168	127

Figure 2.14 Distribution of PHIT - Both Gunners.

Since previous analysis consistently indicated differences between gunners each gunner was modeled separately. In an iterative manner various combinations of the carrier variables were examined in an effort to discover a simple model which would provide a reasonable predictor of PHIT in terms of acceleration and/ or velocity. Initial efforts with linear and polynomial models yielded poor fits. This precluded the simplest of solutions but was expected since these forms do not consider the constraints imposed by the data. PHIT is constrained to lie between zero and one inclusive. These models allow the predicted PHIT to assume values outside this range. Logistic models represent a family of models which satisfy this constraint and the linear logistic model is perhaps the simplest way to represent the dependence of a probability on explanatory variables so that the constraint of lying between zero and one inclusive is satisfied [Ref. 6: p. 18]. This model is defined at Equation 2.1 and was used with good results.

$$\log(PHIT/(1-PHIT)) = X \times BETA \qquad \text{(eqn 2.1)}$$

Refering to Table VI a more detailed explanation of the iterative process used will clarify the results which follow. Column one in this table indicates the independent variables for the particular model while column two indicates the variable coefficient as computed by the linear logistic regression. Columns three and four provide the T-statistic and theoretical T-value used to test the hypothesis that the coefficient is zero with alpha equal .05. Column five indicates the F-significance (1-alpha) of the regression and column six indicates the percentage of variability explained by the regression. Of general note is the * operator used here and elsewhere to denote exponentiation, for example, A*2 means the square of A.

TABLE VI

Selecting the Best Logistic Model-1000 Meters

Gunner 1 1000 Meters Logistic Model

X	BETA	T-Stat	T-.05	F	R*2
I	1.67	4.22	2.04	1.0	.889
V	-.23	.75			
V*2	.02	.64			
A	-.89	1.47			
A*2	-1.47	7.54			
I	.94	1.69	2.03	1.0	.696
V	.09	.69			
A	3.53	8.80			
I	1.43	4.76	2.03	1.0	.884
VxA	-.06	1.02			
A*2	-1.27	13.77			
I	1.21	2.56	2.03	1.0	.703
Vx A*2	-.05	1.15			
A	2.82	5.23			
I	1.46	4.99	2.03	1.0	.887
A	-.17	1.32			
A*2	-1.44	7.75			
I	1.47	4.98	2.03	1.0	.881
A*2	-1.28	16.32			

Gunner 2 1000 Meters Logistic Model

X	BETA	T-Stat	T-.05	F	R*2
I	.96	3.22	2.04	1.0	.889
V	-.01	.03			
V*2	-.01	.51			
A	-1.68	12.14			
A*2	- .78	11.93			
I	.16	.26	2.04	.98	.234
V	-.14	1.34			
A	-.97	2.99			
I	.69	2.54	2.04	1.0	.760
VxA	-.26	7.57			
A*2	-.73	9.04			
I	.39	1.18	2.04	1.0	.635
Vx A*2	-.12	6.24			
A	-1.59	6.43			
C	.66	3.24	2.04	1.0	.867
A	-1.66	11.33			
A*2	-.77	12.73			

Least squares regression using the linear logistic model shown at Equation 2.1 with the explanatory variables shown in column one yielded the statistics shown in Table VI . Looking at the first model for Gunner 1 it is readily apparent that velocity has little effect as a predictor variable. Looking at all the models for Gunner 1 the best overall appears to be the last model. The carrier variable in this model demonstrates nonzero effect and variability explained by the model is high at .881. This model was arrived at by eliminating carrier variables shown to have little effect in previous iterations. As an example the first model gives a bigger R*2 value because it has more terms. In this model the V and V*2 terms demonstrate no significant effect and can be removed with little effect. The same procedure was used for Gunner 2 coincidentally arriving at a similar best fit model in terms of the carrier variables. These models suggest that acceleration has a significant effect on the variability of PHIT at this range with deceleration having a greater effect for Gunner 2. This effect is diminished for acceleration less than one and amplified for values greater than one meter/second-squared. The fact that velocity had no discernable effect among all the models examined is perhaps more important. This suggests that the system filters out the effects of velocity on PHIT at this range. The system is supposed to do this but the analysis now provides objective testimony suggesting that it does.

A similar analysis was conducted for each gunner at each range with the results shown at Table VII . These represent the best models for each range and were obtained through iterative analysis of various combinations of the carrier variables V and A. These models imply that the system does not filter out the effects of velocity as well at increased range as evidenced by the emergence of velocity terms as significant at longer ranges. Comparison of these models shows Gunner 1 to be more affected by velocity than Gunner 2 and Gunner 2 to be less affected in general by target motion than Gunner 1. The different effects of velocity on Gunner 1 were clarified somewhat by examination of residuals which showed most outliers to lie at high values of velocity. Looking at Figures 2.10 and 2.11 we see that Gunner 1 had a fair number of fliers with velocity in the range of 8 to 12 meters/second while Gunner 2 had none. The greater effect could therefore be explained by the fact that Gunner 2 screened out the cause in selecting when to shoot whereas Gunner 1 did not. With the exception of the trials at 2000 meters Gunner 1 seems to be more affected by target motion than Gunner 2. The lesser imputed contribution of target motion towards variability of PHIT for Gunner 2 has no apparent, cogent explanation in the data. It does suggest that other factors not considered such as tracking ability and motivation may have greater effect on Gunner 2 than on Gunner 1.

To unify the description of probability of hit for both gunners over all ranges a common model was selected for all the cases. This model includes both A and A*2 as carriers for both gunners. Table VIII provides a summary for both gunners. From this it can be seen that the majority of the variability in PHIT caused by target motion is explained by acceleration. For both gunners at all ranges the A*2 term is a significant detractor from performance. This would indicate that high values of acceleration or deceleration have a detrimental effect on PHIT while values less than one have little effect. The emergence of the A term as significant at 3000 meters suggests a greater effect of deceleration and smaller values of acceleration at this range for Gunner 1 and at all ranges for Gunner 2. This judgement is partially explained by both gunners' propensity to select more in this range.

TABLE VII

Gunner 1 and 2 Best Logistic Models

Gunner 1

Range	X	BETA	T-Stat	T-.05	F	R*2
1000	I	1.47	4.98	2.03	1.0	.881
	A*2	-1.28	16.32			
2000	I	.49	.75	2.03	1.0	.698
	V	-.43	2.55			
	A*2	-1.65	7.78			
2500	I	.20	.45	2.02	1.0	.858
	VxA	.24	3.69			
	A*2	-1.14	8.61			
3000	I	-.56	.99	2.03	1.0	.873
	V	-.97	5.50			
	A	-1.51	3.33			
	A*2	-1.67	8.98			
All	I	.49	1.48	1.98	1.0	.746
	V	-.36	4.38			
	A	-.68	2.13			
	A*2	-1.64	3.41			

Gunner 2

Range	X	BETA	T-Stat	T-.05	F	R*2
1000	I	.66	3.24	2.04	1.0	.867
	A	-1.66	11.33			
	A*2	-.77	12.73			
2000	I	-1.66	1.86	2.04	1.0	.586
	A	-3.50	4.19			
	A*2	-2.67	6.51			
2500	I	-3.36	2.84	2.05	.999	.443
	A	-1.58	2.29			
	A*2	-1.32	4.60			
3000	I	-1.62	.90	2.06	.999	.486
	V	-.76	2.99			
	VxA	-.31	2.47			
	A*2	-.96	4.31			
All	I	.23	.32	1.98	1.0	.472
	V	-.59	5.13			
	VxA	-1.20	6.05			
	A*2	-.36	9.40			

Figures 2.15 and 2.16 show these logistic models plotted in the applicable range of motion for each gunner. These plots were constructed by solving for p in Equation 2.1 giving an equation for p in terms of acceleration and the regression coefficients. Using the regression coefficients in Table VIII p was then plotted over the range of acceleration observed by the gunner giving the symmetric, bell shaped curves shown. These models indicate a narrow range of acceleration within which any appreciable chance of hit can be expected. The band width of acceleration within which hits can be expected generally decreases significantly past 1000 meters and is considerably wider for deceleration for Gunner 2. Gunner 1 appears to be equally sensitive to acceleration and deceleration since his fitted curves are pretty well centered at acceleration equal to zero.

Examination of residuals for these models showed an irregular cyclic pattern which on closer examination followed the increase and decrease in target motion. In the hopes of achieving a better fit with this model the target motion data was sectioned into one of three categories of change, defined nominally as slow, medium, and fast. The selections keyed on acceleration with the general rule that target acceleration less than one meter/second squared was defined as slow, acceleration greater than two meters /second squared was defined as fast and acceleration between these two values was defined as medium. The time frames for each range of motion are in Table IX while Figures 2.17 through 2.20 show these sections visually.

Using this sectioning the A, A*2 logistic model was applied to each gunner for each section at each range with the results shown at Table X . The first column in this table indicates the three sectioned models for each range. Reading across for the slow model at 1000 meters for Gunner 1 the second column indicates that the constant term had significant effect with a coefficient value of 1.46 as

TABLE VIII

Gunner 1 and 2 A, A*2 Logistic Models

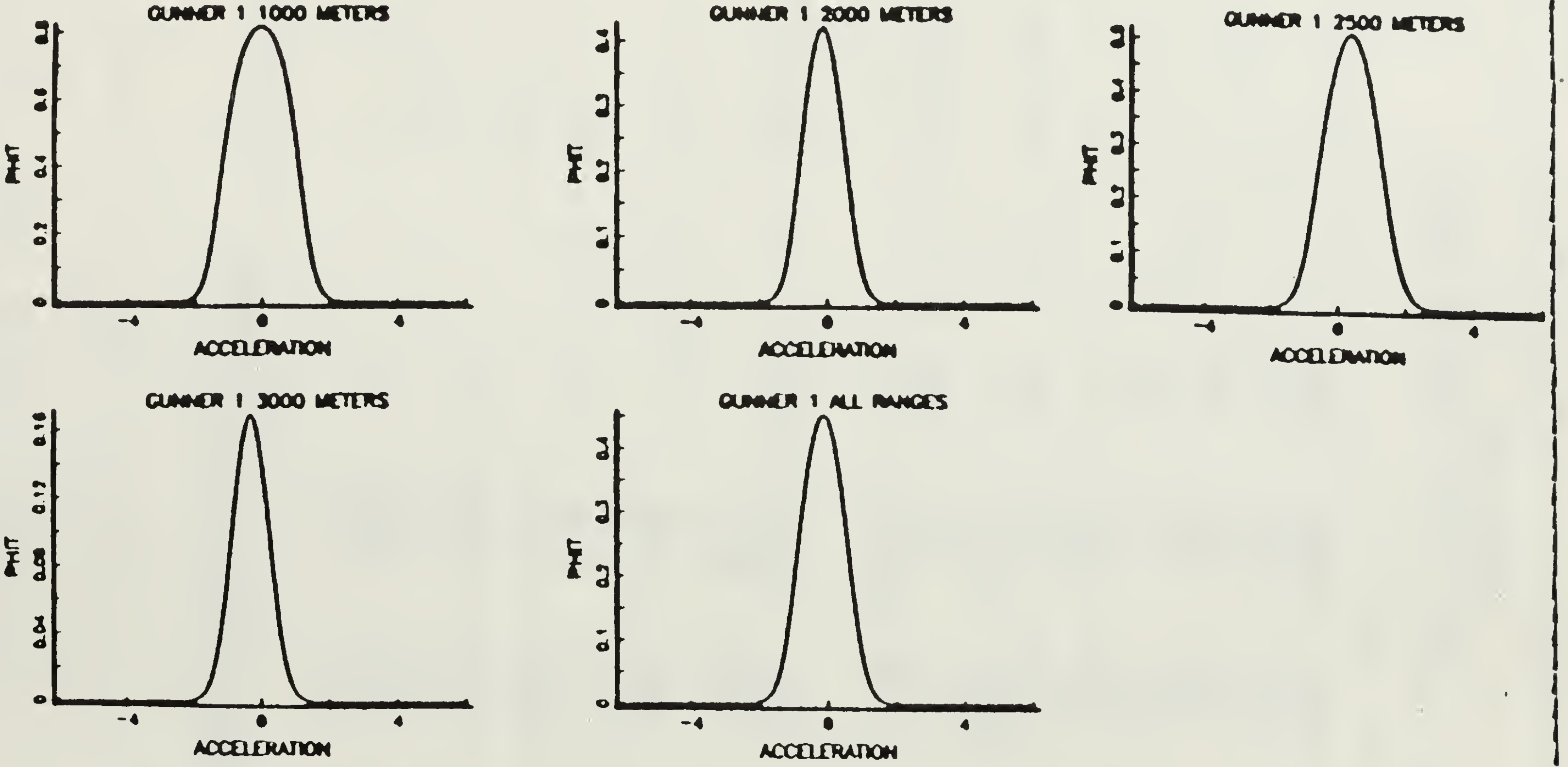
Gunner 1

Range	X	BETA	T-Stat	T-.05	F	R*2(Best)
1000	I	1.46	4.99	2.03	1.0	.887
	A	-.17	1.32			
	A*2	-1.44	7.75			
2000	I	-.35	.55	2.01	1.0	.661(.698)
	A	-.47	.84			
	A*2	-2.03	7.97			
2500	I	-.12	.24	2.02	1.0	.818(.858)
	A	.89	1.39			
	A*2	-1.17	4.90			
3000	I	-1.79	2.57	2.03	1.0	.763(.873)
	A	-1.25	2.06			
	A*2	-1.95	8.13			
All	I	-.23	.75	1.98	1.0	.716(.746)
	A	-.49	1.47			
	A*2	-1.70	13.19			

Gunner 2

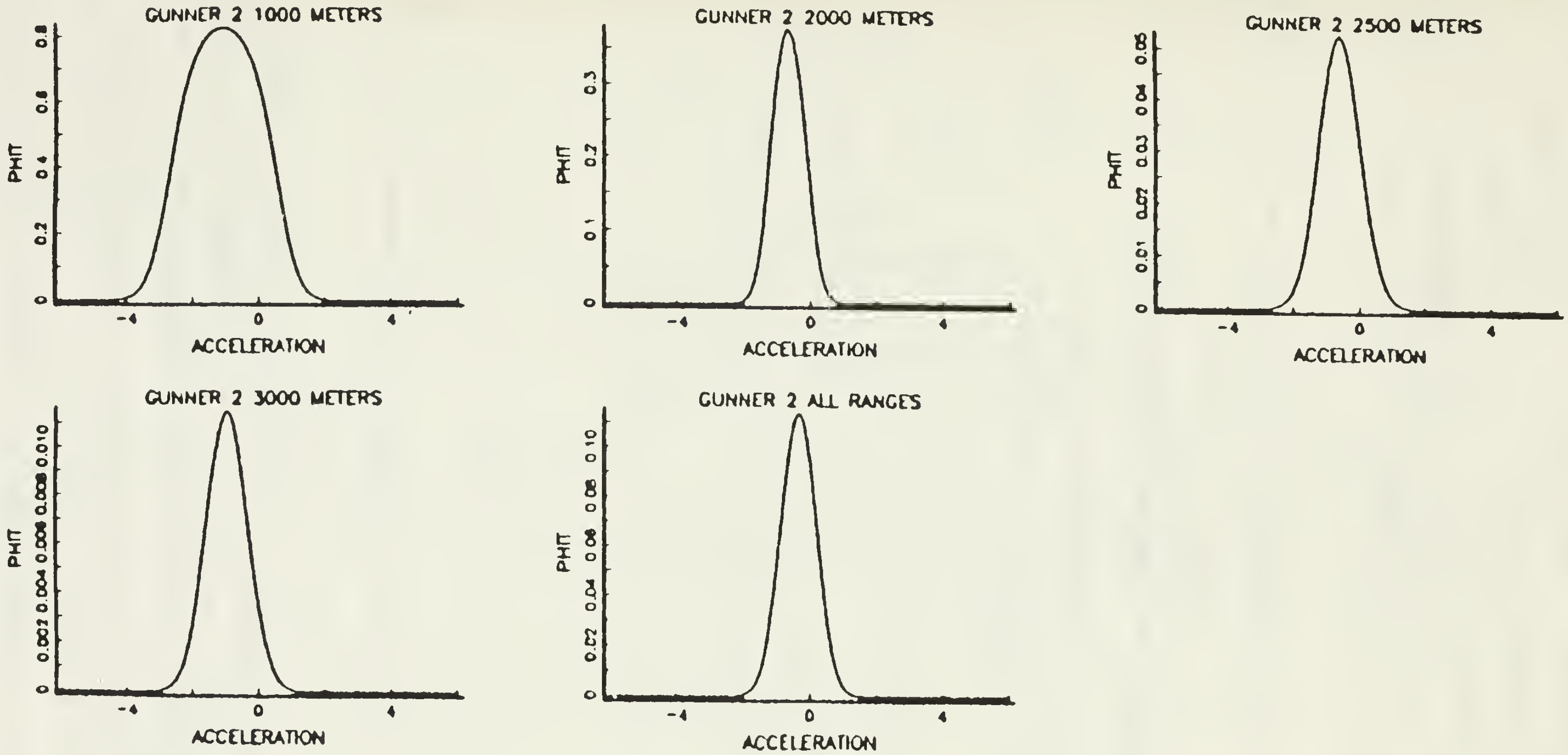
Range	X	BETA	T-Stat	T-.05	F	R*2(Best)
1000	I	.66	3.24	2.04	1.0	.867
	A	-1.66	11.33			
	A*2	-.77	12.73			
2000	I	-1.66	1.86	2.04	1.0	.586
	A	-3.50	4.19			
	A*2	-2.67	6.51			
2500	I	-3.36	2.84	2.05	.999	.443
	A	-1.58	2.29			
	A*2	-1.32	4.60			
3000	I	-5.63	4.15	2.06	.991	.309(.486)
	A	-2.47	1.99			
	A*2	-1.30	3.20			
All	I	-2.92	4.15	1.98	1.0	.366(.472)
	A	-1.90	4.66			
	A*2	-1.35	8.45			

Note: R*2(Best) refers to the R*2 value obtained with the best models as shown in Table VII .



Note:Scale of y-axis (PHIT) is different for each plot.

Figure 2.15 Plotted A, A*2 Models - Gunner 1.



Note:Scale of y-axis (PHIT) is different for each plot.

Figure 2.16 Plotted A, A*2 Models - Gunner 2.

computed by the regression. The third column indicates that the A term had no significant effect for this model. The fourth column indicates that the A*2 term also had no significant effect for this model. The fifth column labeled F indicates that the F-significance(1-alpha) for this model is .28 . The sixth column is the R*2 value for this model and the last column indicates the number of observations(shots) falling in the slow range of target motion. The sectioned models are for the most part not significant as predictors. Most of the coefficients are not significant and where they are the variability explained by the model is

TABLE IX

Sectioning of Target Acceleration

	MOTION DEFINITION AT TIME		
Time (seconds)	Slow	Moderate	Fast
0 - 3			x
3 - 19	x		
19 - 35			x
35 - 60		x	
60 - 66			x
66 - 100	x		
100 - 112		x	
112 - 138			x
138 - 162	x		
162 - 170		x	
170 - 183	x		
183 - 212			x

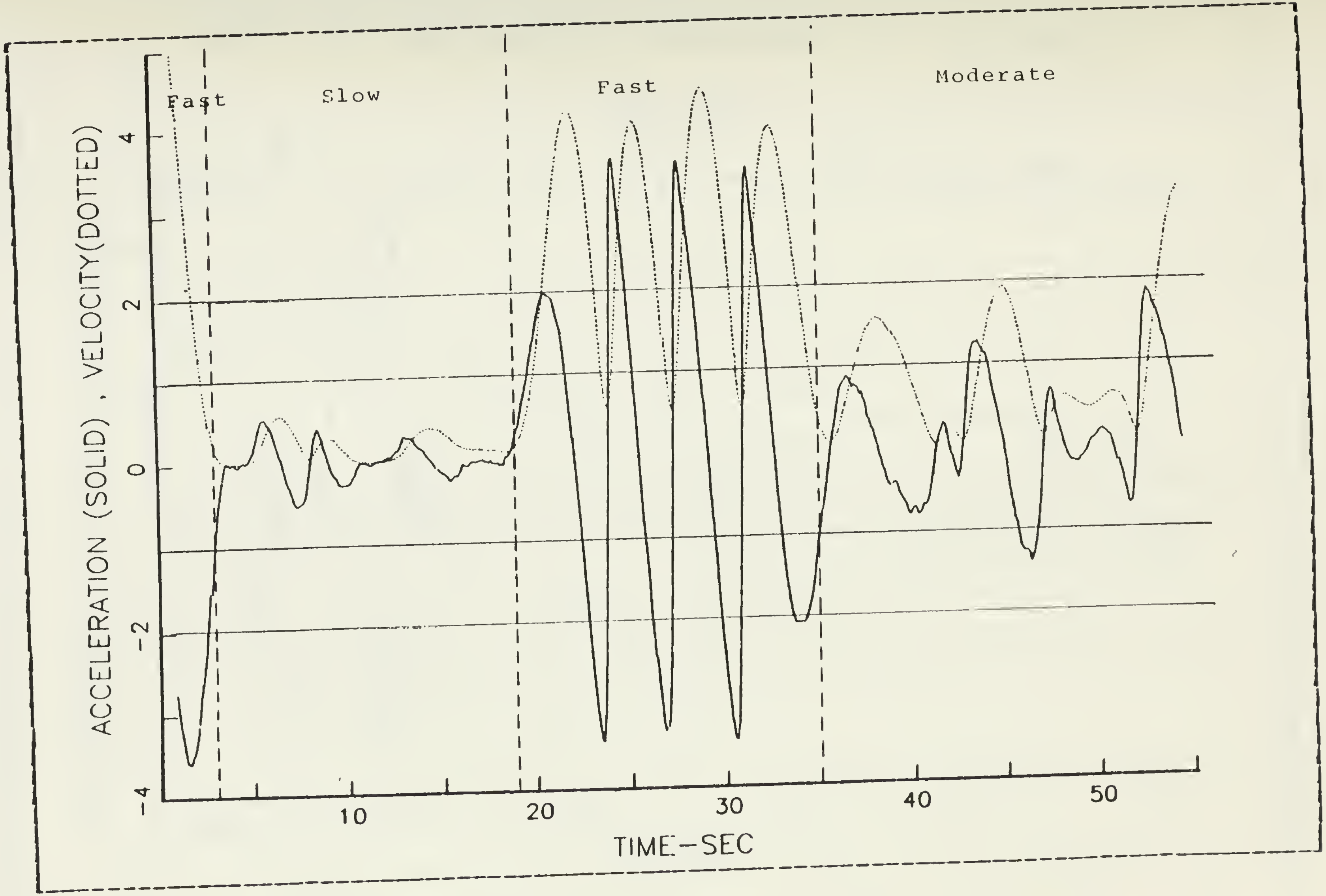


Figure 2.17 Sectioning of Target Motion - 0 - 55 Seconds.

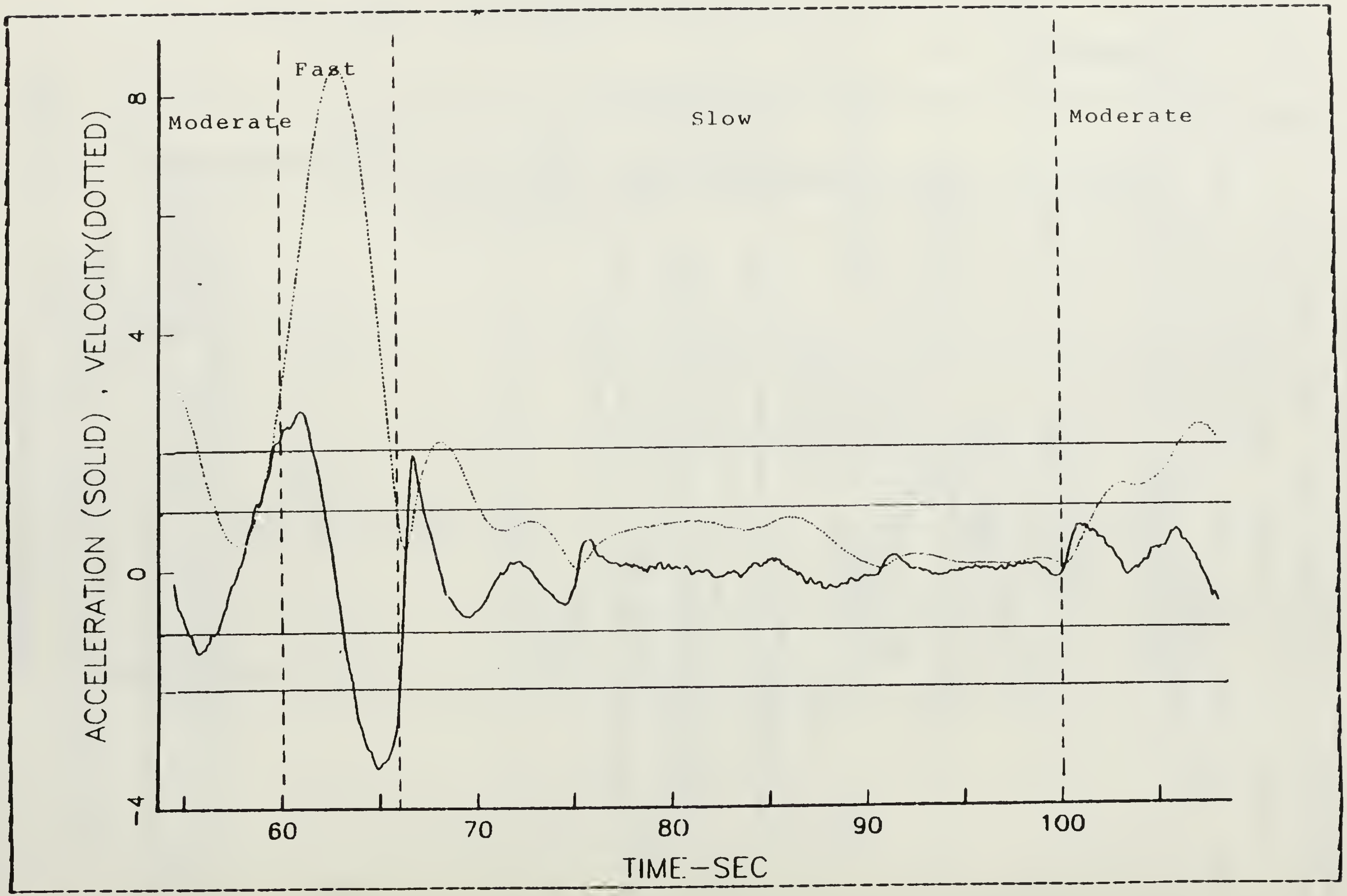


Figure 2.18 Sectioning of Target Motion - 55 - 110 Seconds.

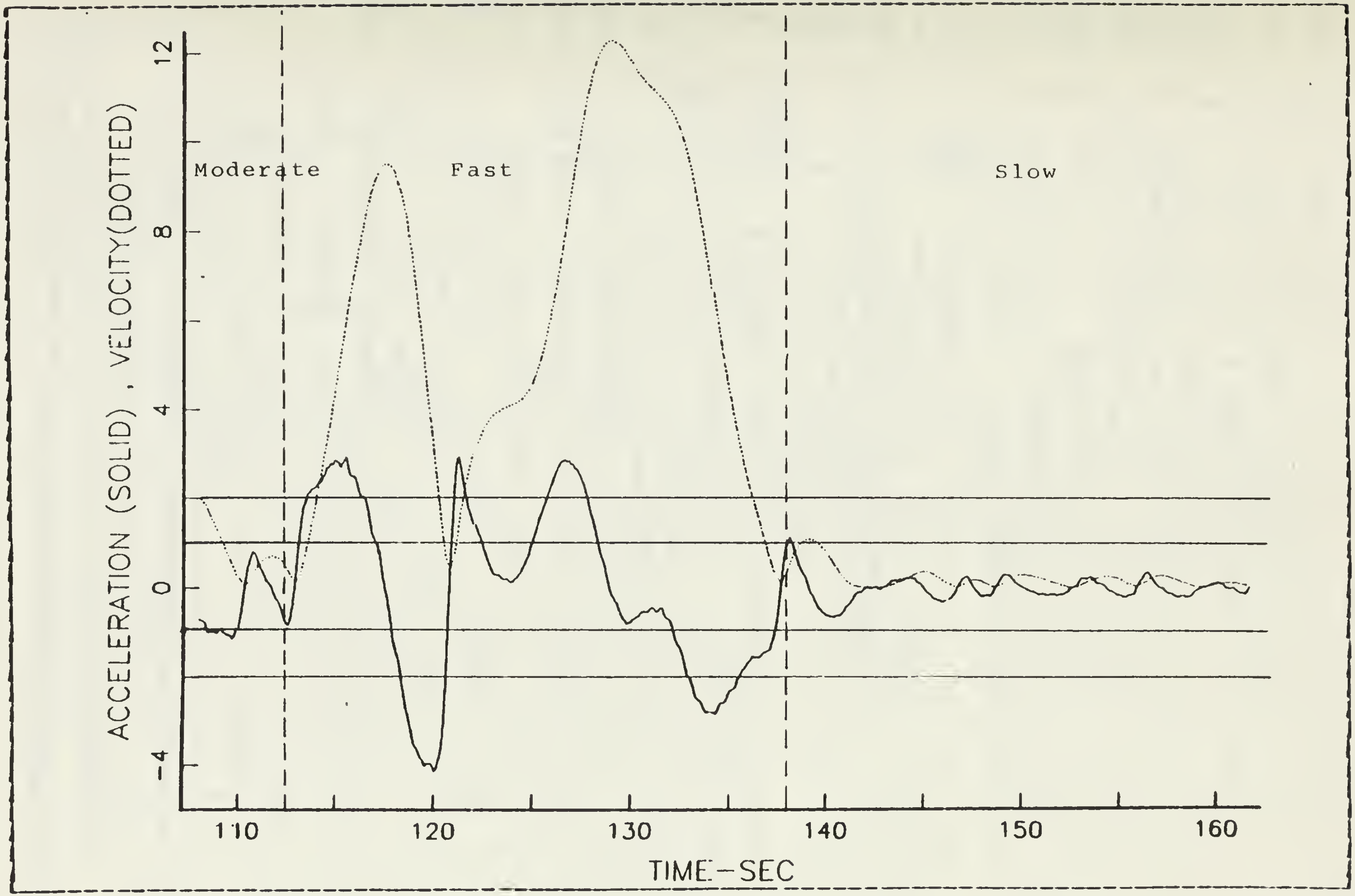


Figure 2.19 Sectioning of Target Motion - 110 - 165 Seconds.

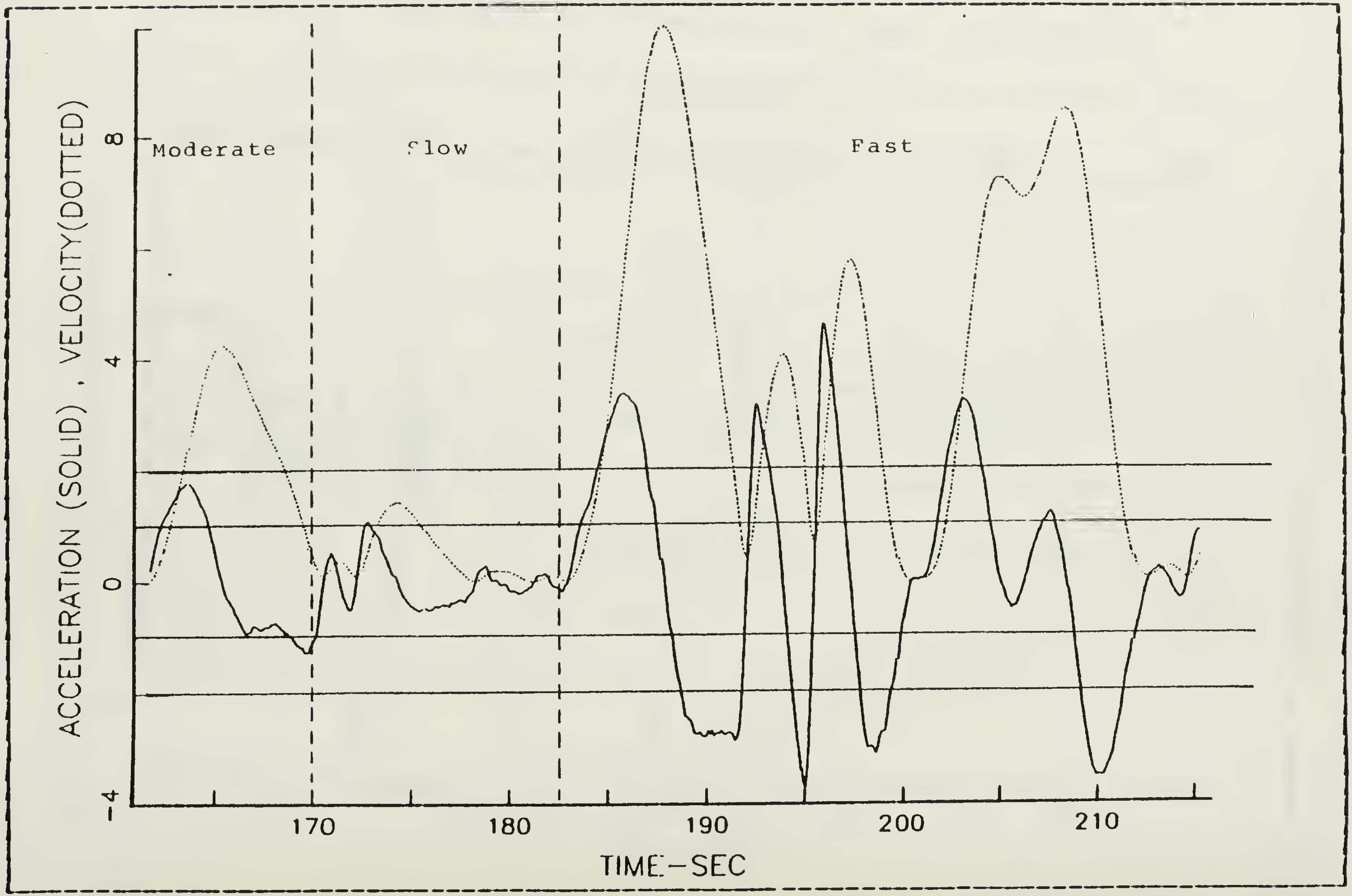


Figure 2.20 Sectioning of Target Motion - 165 - 215 Seconds.

to the dependent and/or carrier variables or some type of pattern in most cases. The two exceptions to this rule are the fast models for both gunners at 1000 meters. These models show high levels of significance with non-zero coefficients and high R-square values. They additionally display patternless residuals. Figure 2.21 and 2.22 show the plotted equations for all models with F-significance greater than .95 . These sectioned models generally indicate a narrow range of acceleration within which any chance of hit can be expected. This range is generally wider for deceleration but there are exceptions to this rule for Gunner 1 who as with previous models appears to be equally sensitive to acceleration and deceleration as evidenced by his fitted curves being centered at acceleration equal to zero.

Analysis of variance data for the total and sectioned A, A*2 models is contained in Table XI . The first column in this table indicates the Gunner, the range and the source of variation. MEAN indicates variation due to the grand mean, REG. indicates variation due to regression, RESD. indicates variation due to residuals, and TOTAL indicates total variation. Columns two and three under the heading TOTAL(for total unsectioned A, A*2 model) indicate the sum of squares(SS) and mean square(MS) error for each source for each model. Similar entries under the heading SLOW indicate the sum of squares and mean square for the slow sectioned A, A*2 model. Entries under the heading MEDIUM and FAST are for the respective sectioned A, A*2 model. This data generally shows an increase in mean square residuals with an increase in range or an increase in target motion. The fast model for Gunner 1 at 1000 meters shows a relatively good fit. On closer examination however the mean square residuals for this model are worse than for the total model indicating a looser fit even though explained variability

TABLE X

Sectioned Model - A, A*2

Gunner 1

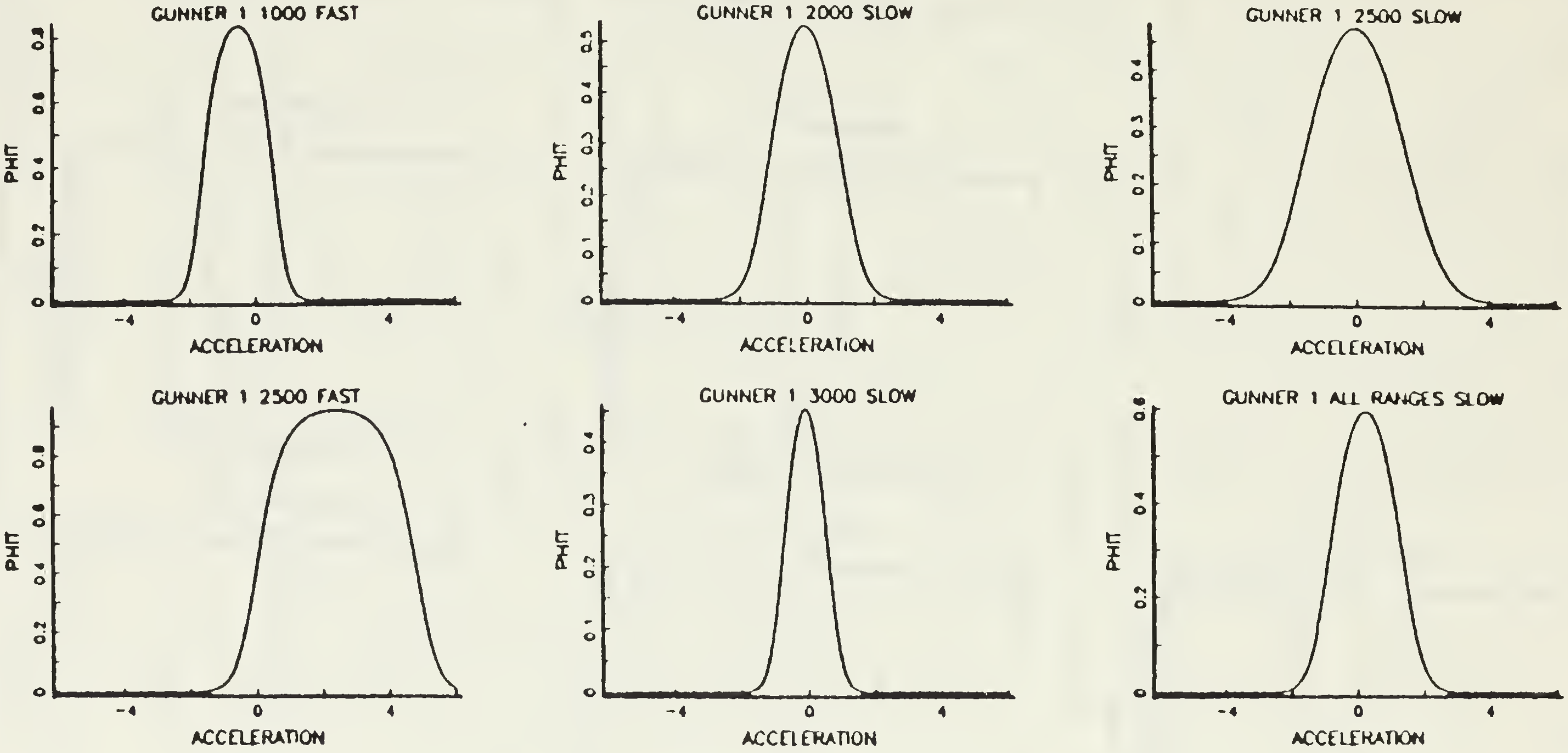
Range BETA = 0 (alpha = .05)

Range	I	A	A*2	F	R*2	Obs.
1000						
slow	1.46	yes	yes	.28	.05	15
med.	yes	yes	yes	.18	.06	9
fast	yes	yes	1.77	1.0	.878	14
2000						
slow	yes	yes	-.95	.99	.56	17
med.	yes	yes	yes	.45	.10	14
fast	yes	yes	yes	.24	.04	18
2500						
slow	yes	yes	-.40	.99	.52	16
med.	yes	yes	yes	.70	.33	9
fast	yes	yes	yes	.99	.73	17
3000						
slow	-.21	yes	-2.28	.99	.55	15
med.	yes	yes	yes	.54	.40	6
fast	-10.12	yes	yes	.89	.25	18
All						
slow	.34	yes	-1.02	.99	.15	65
med.	yes	yes	yes	.65	.06	38
fast	-8.81	yes	yes	.02	.00	67

Gunner 2

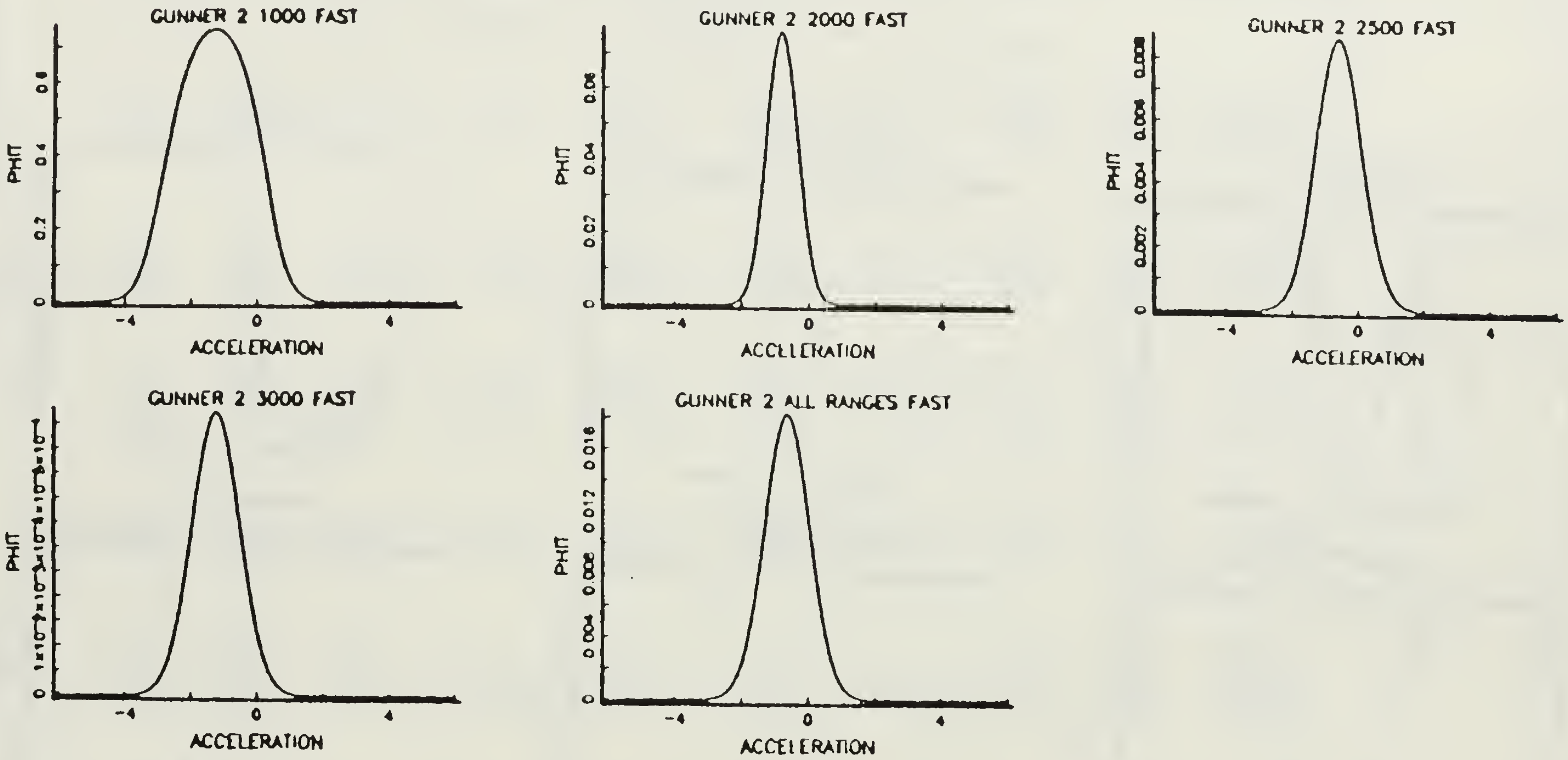
Range BETA = 0 (alpha = .05)

Range	I	A	A*2	F	R*2	Obs.
1000						
slow	1.45	yes	yes	.15	.05	9
med.	yes	yes	yes	.03	.01	6
fast	yes	-1.83	-1.69	1.0	.942	20
2000						
slow	.21	yes	yes	.53	.32	7
med.	-.52	yes	yes	.69	.45	7
fast	-.40	-3.73	-2.37	.99	.54	19
2500						
slow	yes	yes	yes	.71	.71	5
med.	yes	yes	yes	.88	.65	7
fast	-5.06	yes	-1.05	.97	.36	18
3000						
slow	yes	yes	yes	.71	.71	5
med.	yes	yes	yes	.45	.45	5
fast	-8.92	yes	-.96	.89	.23	19
All						
slow	2.44	yes	yes	.03	.31	26
med.	yes	yes	-1.85	.95	.24	25
fast	-4.45	-1.93	-1.09	1.0	.30	76



Note:Scale of y-axis (PHIT) is different for each plot.

Figure 2.21 Plotted Sectioned A, A*2 Models-Gunner 1.



Ncte:Scale of y-axis (PHIT) is different for each plct.

Figure 2.22 Plotted Sectioned A, A*2 Models-Gunner 2.

remains high. The fast model for Gunner 2 shows the opposite in that the sectioned model has smaller mean square residuals indicating a tighter fit with higher explained variability. Of minor interest is the jump in mean square residual for Gunner 1 at 2000 meters for the total and fast section model. This is just one additional departure from trend which goes with this trial. The net results one draws from the models must be buffered with qualifiers. The assumptions for regression are not tested and informal analysis shows them to be weakly supported in some cases. The models tend to amplify the differences between gunners and this trend combined with previous analysis is significant and should not be ignored. The persistance of acceleration squared as a significant explanatory variable is another trend which should not be ignored. This is also supported by previous analysis in that trained gunners seem to screen out this factor which the models in general show detracts from performance. The final salient point brought forth by the models is the conspicuous absence of velocity as an explanatory variable. Here what the models do not say is important because it suggests that the total gun system filters out the effects of velocity. This trend is more pronounced at close range and more so for Gunner 2 than Gunner 1. The models further indicate that for each gunner there is some threshold of acceleration beyond which hits cannot be expected. This threshold appears to be less sensitive to deceleration. This suggests that gunners can anticipate target motion better when the target is decelerating or they can track better in this condition or a combination of both these factors.

TABLE XI

ANOVA - Sectioned Models, Gunner 1 and 2

Gunner 1

	Total Model SS/MS		Sectioned Model SS/MS					
1000	TOTAL		SLOW		MEDIUM		FAST	
SOURCE	SS	MS	SS	MS	SS	MS	SS	MS
MEAN	12		33.1		4.2		176	
REG.	736	368	.037	.018	.4	.18	545	272
RESD.	94	2.7	.637	.053	5.7	.95	76	6.9
TOTAL	842	22	34	2.25	10.3	1.14	797	57
2000								
MEAN	629		.0		22.4		373	
REG.	1147	574	.7	.33	18.6	9.3	29	14.6
RESD.	589	12.8	.5	.04	160	14.6	760	50.6
TOTAL	2364	48.2	1.2	.07	201	14.4	2161	120
2500								
MEAN	549		.6		3.3		1208	
REG.	1162	581	.5	.25	.7	.33	552	276
RESD.	259	6.7	.4	.04	1.3	.22	204	14.5
TOTAL	1970	47	1.5	.10	5.3	.59	1964	116
3000								
MEAN	1616		3.0		4.8		3171	
REG.	1318	659	.8	.42	1.0	.5	40.6	20.3
RESD.	410	11.4	.7	.06	1.5	.5	121	8.1
TOTAL	3345	86	4.5	.30	7.3	1.2	3332	185
All Ranges								
MEAN	2284		2.2		13.2		5179	
REG.	1916	958	5.7	2.5	12.3	6.1	.5	.25
RESD.	3321	26.8	33	.55	199	5.7	3076	48
TOTAL	7521	59.2	41	.65	224	5.8	8256	123

Gunner 2

	Total Model SS/MS				Sectioned Model SS/MS			
1000	TOTAL		SLOW		MEDIUM		FAST	
SOURCE	SS	MS	SS	MS	SS	MS	SS	MS
MEAN	.3		19.6		1.7		8.6	
REG.	210	105	.0	.01	.0	.02	198	99
RESD.	32	1	.4	.07	2.9	.95	12	.72
TOTAL	242	6.9	20	2.23	4.6	.76	218	11
2000								
MEAN	645		.35		.28		1123	
REG.	775	387	.01	.002	.41	.20	459	229
RESD.	548	18.3	.01	.002	.50	.12	385	24
TOTAL	1968	59.6	.37	.052	1.2	.17	1966	104
2500								
MEAN	1030		.03		134		1165	
REG.	590	295	.01	.005	171	85	290	145
RESD.	740	27.4	.00	.002	90	23	571	34
TOTAL	2360	78.7	.04	.009	395	56	1966	109
3000								
MEAN	1673		1.4		63		2102	
REG.	394	197	.2	.117	61	31	154	77
RESD.	883	34	.1	.048	76	38	492	31
TOTAL	2950	102	1.7	.353	200	40	2748	145
All Ranges								
MEAN	2140		5.3		87		3340	
REG.	4567	2283	.5	.27	122	61	1053	526
RESD.	1813	10.9	16	.71	392	18	2504	34
TOTAL	8521	50.7	22	.86	600	24	6898	91

III. CONCLUSIONS AND RECOMMENDATIONS

A main thrust of this analysis was to characterize the target motion in the neighborhood of trigger pull. The experiment was not conducted with this specific purpose in mind. It was, on the contrary suggested as an interesting question to be considered after review of the results in their intended role. Originators of the experiment felt that answering this question would provide insight into the factors that make trained gunners proficient and so it has.

The analysis provides statistical, objective basis for the statement that trained gunners have a selection criteria and it goes a long way in clarifying just what they do and do not look for in terms of target motion as they pick shots. The analysis characterizes target motion during the period when gunners formulate the decision to shoot and indicates that they generally look for a pattern of increasing followed by decreasing acceleration with deceleration, or acceleration approaching zero being the prefered parameter values just prior to trigger pull. Velocity does not appear to be a significant determinant of when gunners shoot except that they elect not to shoot as often as expected(assuming random selection) at very high or very low values of velocity or more appropriately extremes of the range of velocity they observe. This was intuitively expected since the faster a target moves the harder it is to hit, generally speaking.

These general guidelines vary between the two gunners examined suggesting that hard and fast rules may not produce the best overall results among many different gunners. In general Gunner 1 has a more stringent criteria for prefered target motion yet he fires more often suggesting he does not track as long on average to pick a shot. Intuitively he appears to anticipate the targets motion and ambush the target within his prefered range of motion. If the general goals of the two gunners are the same then Gunner 1 achieves the goal of shooting during deceleration better than Gunner 2 with slightly better hit performance being the result. It does appear however that both gunners seek acceleration approaching zero and in this respect Gunner 2 does slightly better. The techniques are different and what works for one gunner might not work for another. In any event the achieved results are very close and either emphasis or combination thereof might work well for any given gunner.

In an attempt to better quantify these findings hit performance was modeled in terms of target motion using the logistic regression. This exersize proved most significant in what it did not show. For the many models examined target velocity was found to have no significant effect at ranges up to 1000 meters and inconsistent effect, no effect or minimal effect at longer ranges. Contrasting this the models demonstrate that acceleration has significant and consistent effect on hit performance at all ranges. This would suggest that the trained gunners' selection criteria is basically sound and that the gun system, the gunner, or both effectively filter out the effects of velocity on hit performance, particularly at close range.

These results suggest that training procedures which develop the gunners' ability to discriminate target acceleration would improve hit performance. Among the most simple procedures would be to teach gunners to look for head on, tail on, or oblique crossing target silhouettes as opposed to a perpendicular crossing target silhouette. Since trained gunners were able to pick out these types of motion without benefit of a target silhouette in the experiment it is probable that simulators could be designed to mimic good and bad types of target motion thereby building and reinforcing good shot selection habits in other gunners. The simulator used in the experiment might even be suitable for this purpose other constraints not withstanding.

APPENDIX A

COMPUTER PROGRAMS

The APL function 'IN' takes a small vector of times at trigger pull and locates their position in a much larger vector of time. The result is a vector of zeros and ones equal in length to the large vector with ones indicating the position of a time from the small vector in the large vector. The small vector must be ordered. Both vectors must have all entries significant to the same decimal place.

```
       ∇IN[⎕]
      ∇ R←A IN B;STOP;COUNT;COUNT2;TEMP;HOLD
[1]   ⍝A IS THE VECTOR OF TIMES AT TRIGGER PULL
[2]   ⍝A MUST BE ORDERED FROM LOW TO HIGH
[3]   ⍝B IS THE TOTAL TIME VECTOR
[4]    STOP←⍴A
[5]    COUNT←0
[6]    COUNT2←1
[7]    HOLD←(1↑A)=B
[8]    COUNT←COUNT+1
[9]    COUNT2←COUNT2+1
[10]   TEMP←(COUNT↓(COUNT2↑A))=B
[11]   HOLD←HOLD+TEMP
[12]   →5×⍳COUNT≤STOP
[13]   R←HOLD
      ∇
[14]  .
```

The APL function 'DECISION' takes a small vector of times at trigger pull and computes the average velocity and acceleration during the period .18 to .22 seconds prior to each time. Times must be ordered. The overall time, velocity, and acceleration vectors must be in the workspace as must the function 'IN'.

```
       ∇DECISION[⎕]
      ∇ R←DECISION X
[1]   ⍝X IS THE TIME OF TRIGGER PULLS A 1-DIMENSIONAL VECTOR.
[2]   ⍝THIS FUNCTION COMPUTES THE AVERAGE VELOCITY AND ACCELERATIO
N
[3]   ⍝AT TRIGGER PULL MINUS .18 SEC TO TRIGGER PULL MINUS .22 SE
C
[4]   ⍝THESE AVERAGES ARE USED TO REPRESENT VELOCITY AND ACCELERAT
ION
[5]   ⍝AT TIME OF DECISION TO PULL THE TRIGGER.
[6]   ⍝NOTE X MUST BE X←X[⍋X] OR ORDER TIMES FROM LOW TO HIGH
[7]    T←(X-0.18)
[8]    TSEL←T IN TIME
[9]   ⍝USE NEXT LINE WHEN DOMAIN ERROR OCCURS DUE TO OVERLAP
[10]  ⍝TSEL←(TSEL≥1)
[11]  ⍝NOTE FUNCTION 'IN' MUST BE PRESENT IN THE SAME WS
[12]   V←V1←(TSEL/VEL)
[13]   A←A1←(TSEL/NACEL)
[14]   I←1
[15]  LOOP:TEMPV←((I⊖TSEL)/VEL)
[16]   TEMPA←((I⊖TSEL)/NACEL)
[17]   V←(V+TEMPV)
[18]   A←(A+TEMPA)
[19]   I←I+1
[20]   →LOOP×⍳(I≤4)
[21]   V←(V÷5)
[22]   A←(A÷5)
[23]  ⍝V AND A ARE THE AVERAGE VELOCITY AND ACCELERATION
[24]  ⍝FROM TP(TRIGGER PULL)-.22 TO TP -.18
[25]   R←'REASSIGN V AND A'
      ∇
[26]   .
```

The APL function 'SAMPLE' takes a small vector of times at trigger pull and computes the average velocity and acceleration during any half second interval specified. Times must be ordered. The overall time, velocity, and acceleration vectors must be in the workspace as must the function 'IN'.

```
      ∇SAMPLE[⎕]
     ∇ R←N SAMPLE X
[1]   ⍝ N IS THE TIME PRIOR TO TP THAT STARTS SAMPLE WINDOW
[2]   ⍝ IF N = .2 THE AVERAGES RETURNED WILL BE FOR THE PERIOD
[3]   ⍝TP - .2(DECISION POINT) TO TP -.7 OR ONE SAMPLE PERIOD
[4]   ⍝PRIOR TO THE TIME OF DECISION TO PULL
[5]   ⍝X IS THE VECTOR OF TIMES AT TRIGGER PULL - THIS VECTOR
[6]   ⍝MUST BE ORDERED FROM LOW TO HIGH
[7]    T←(X-N)
[8]    TSEL←T IN TIME
[9]   ⍝NOTE FUNCTION 'IN'MUST BE PRESENT IN WS
[10]   V←V1←(TSEL/VEL)
[11]   A←A1←(TSEL/NACEL)
[12]   I←1
[13]  LOOP:TEMPV←((I⊖TSEL)/VEL)
[14]   TEMPA←((I⊖TSEL)/NACEL)
[15]   V←(V+TEMPV)
[16]   A←(A+TEMPA)
[17]   I←I+1
[18]   →LOOP×⍳(I≤49)
[19]   V←V÷50
[20]   A←A÷50
[21]  ⍝V AND A ARE THE AVERAGE VELOCITY AND ACCELERATION
[22]  ⍝FROM TP(TRIGGER PULL)-N  TO TP -(N+.5)
[23]   R←'REASSIGN V AND A'
     ∇
[24]   .
```

The program 'PICTPROB' computes the number of data points in a cell and the proportion of data points in a cell. The cell boundries are specified by the user in the vectors ACELL and VCELL. The overall time, velocity, and acceleration vectors must be in the workspace.

```
        ∇PLOTPROB[⎕]
       ∇ R←V PLOTPROB A
[1]   ⍝COMPUTES THE NUMBER OF DATA POINTS IN A CELL AND THE
[2]   ⍝PROPORTION OF DATA POINTS IN A CELL
[3]   ⍝USER DEFINES ACELL AND VCELL WHICH ARE THE CELL BOUNDRIES
[4]   ⍝ACELL AND VCELL MUST BE TO THE 3D DECIMAL (DATA IS TO 2D DE
CIMAL)
[5]    CTOT←⍳0
[6]    AL←1↑ACELL
[7]    AR←1↑1↓ACELL
[8]    ATOT←AL
[9]    I←0
[10]  LOOP2:J←0
[11]   VL←1↑VCELL
[12]   VR←1↑1↓VCELL
[13]   VTOT←VL
[14]   ATOT←ATOT,AR
[15]  LOOP:CIJ←+/(((V≥VL)∧(V≤VR))∧((A≥AL)∧(A≤AR)))
[16]   CTOT←CTOT,CIJ
[17]   J←J+1
[18]   VL←VR
[19]   VTOT←VTOT,VL
[20]   VR←1↑(J+1)↓VCELL
[21]   →LOOP×⍳(J<(((⍴VCELL)-1))
[22]   I←I+1
[23]   AL←AR
[24]   AR←1↑(I+1)↓ACELL
[25]   →LOOP2×⍳(I<(((⍴ACELL)-1))
[26]   NDAT←⊖((((⍴ACELL)-1),((⍴VCELL)-1))⍴CTOT))
[27]   PSEL←NDAT÷(+/,NDAT)
[28]   R1←'NDAT IS NUMBER OF DATA POINTS IN A CELL   '
[29]   R2←'PSEL = PROPORTION OF DATA POINTS IN A CELL'
[30]   R← 2 42 ⍴(R1,R2)
       ∇
[31]   .
```

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